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YOUNG OF THE ATLANTIC SAILFISH, *ISTIOPHORUS PLATYPTERUS*[1]

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ABSTRACT

One hundred fifty-four Atlantic sailfish, 26.1 to 216 mm. in standard length, were dip netted on cruises of the Bureau of Commercial Fisheries charter vessel *Silver Bay* off the south Atlantic Coast of the United States in 1960 and 1962. This group of specimens (larger than any previously available collection of sailfish of similar size) was examined to determine changes during development. Thirty-four eastern Atlantic specimens 13.8 to 238 mm. in standard length that were dip netted in 1968 on a cruise of the Bureau's vessel *Undaunted* in the Gulf of Guinea were compared with the specimens from the western Atlantic.

Five western Atlantic specimens are illustrated. Loss of larval characteristics and development of fins and fin rays and pigmentation are discussed. Correlations of numbers of fin rays and statistics describing relationships of measurements of selected body parts for western Atlantic specimens are presented. Principal differences between eastern and western Atlantic specimens are the slightly longer pectoral fin, snout, and head in eastern Atlantic specimens.

Collections of the young stages of Istiophoridae that include a sufficient number of larvae and juveniles for detailed studies of developmental stages are rare. The literature on young Atlantic sailfish, *Istiophorus platypterus* (Shaw and Nodder),[2] is primarily on small larvae and has information on only 21 specimens longer than 25 mm. SL (standard length)—(Voss, 1953, 4 specimens 29.5–208 mm.; Gehringer, 1957, 16 specimens 27.4–101 mm.; and de Sylva, 1963, 1 specimen, 167 mm.).

This paper is based primarily on a collection of 154 sailfish from the western Atlantic Ocean, 26.1 to 216 mm. SL. They were collected at dip net and nightlight stations on cruises of the BCF (Bureau of Commercial Fisheries) charter vessel *Silver Bay* off the southeastern coast of the United States in June and July 1960 and September and October 1962. Subsequent to my examination of the western Atlantic specimens and preparation of a draft of a manuscript describing them, I examined 34 specimens, 13.8 to 238 mm. SL (all but 1 over 25 mm. SL), collected by dip net at nightlight stations on a cruise of the BCF vessel *Undaunted* in the Gulf of Guinea, off the west coast of Africa, in April 1968.

For western Atlantic specimens I include detailed line drawings of a developmental series, statistics showing the relationships of measurements of selected body parts, and discussions of dorsal and anal fin rays and changes during their development. I compare eastern and western Atlantic specimens of similar size and include in my discussion of western Atlantic material those variations I found in eastern Atlantic material.

METHODS AND DATA

MEASUREMENTS

Measurements were made with dial calipers calibrated in 0.1-mm. units and are recorded to the nearest 0.1 mm. if less than 100 mm. or to the nearest millimeter if 100 mm. or greater.

DEFINITIONS OF TERMS

I consider all specimens in this study to be juveniles, by definition of the juvenile stage as sexually immature specimens whose numbers of fin rays are within the ranges for the adult.

Measurements

Standard length, head length, snout length, pectoral and pelvic fin lengths, eye diameter, and

[1] Contribution No. 95 from the Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Ga. 31520.

[2] In using the name *Istiophorus platypterus* (Shaw and Nodder), I follow Morrow and Harbo (1969).

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pterotic and main preopercular spine lengths are as defined by Gehringer (1957). Trunk length is the distance between the posteriormost margin of the orbit and anterior point of emergence of the upper keel on the caudal peduncle on specimens 85 mm. SL or longer (de Sylva, 1957). On specimens smaller than about 85 mm. SL, which lack keels, the posterior point for this measurement is the insertion of the leading edge of the finfold of the dorsal lobe of the caudal fin. This point is directly above the anterior edge of the caudal keel on larger specimens. Body length is the distance between the tip of the mandible and the tips of the midcaudal fin rays (Rivas, 1956). Body depth is a vertical measurement at the insertion of the first pelvic fin ray. Pelvic fin to anal fin is the distance between the insertion of the first pelvic fin ray and the insertion of the first anal fin ray.

Fin Rays

The dorsal and anal fins are single fins in the larval and juvenile stages, but in the adult the terminal six or seven rays of both fins are separated from anterior portions of these fins to form second dorsal and anal fins. The fins are not divided in the largest specimens in this study, 216 to 238 mm. SL, although the anal fin is nearly divided. Even on my smallest western Atlantic specimen (26.1 mm. SL), the shape and size of the terminal six or seven rays distinguish them from the few, less robust, more widely spaced rays immediately ahead of them (which are overgrown with tissue in the adult). I recorded ray counts separately for the anterior and posterior portions of both dorsal and anal fins. The terminal ray in the dorsal and anal fins though divided to its base, is recorded as one ray.

STUDY MATERIAL

Western Atlantic specimens are from *Silver Bay* cruises, all taken by dip net at the surface, under a nightlight: Sta. 2139: 29°55′ N., 80°38′ W. (about 35 nautical miles E. of St. Augustine, Fla.); 2045–2245 hours, June 12, 1960; 33 m., surface temperature 25.6° C.; 3 specimens, 81.9 to 155 mm. SL. Sta. 2172: 35°00′ N., 75°19′ W. (about 20 nautical miles SE. of Cape Hatteras, N.C.); 2200–0250 hours, July 18–19, 1960; 146 to 366 m., surface temperature 27.3° C.; 10 specimens, 67.1 to 216 mm. SL. Sta. 2201: 34°34′ N., 75°40′ W. (about 50 nautical miles E. of Cape Lookout, N.C.); 0030–0400 hours, July 24, 1960; 146 to 165 m., surface temperature 28.9° C.; 135 specimens, 26.1 to 167 mm. SL. Sta. 2268: 32°36′ N., 78°30′ W. (about 70 nautical miles E. of Charleston, S.C.); 0115–0300 hours, July 29, 1960; 190 to 198 m., surface temperature 28.9° C.; 4 specimens, 37.1 to 91.1 mm. SL. Sta. 4326: 28°32′ N., 80°03′ W. (about 25 nautical miles E. of Cape Kennedy, Fla.); 2310–0115 hours, September 3–4, 1962; 70 m., surface temperature 27.8° C.; 1 specimen, 137 mm. SL. Sta. 4403: 28°56′ N., 80°25′ W. (about 30 nautical miles N. of Cape Kennedy, Fla.); 2345–0145 hours, October 4–5, 1962; 24 m., surface temperature 28.9° C.; 1 specimen, 169 mm. SL.

Eastern Atlantic specimens are from *Undaunted* Cruise 6801, all taken by dip net at the surface, under a nightlight: Sta. 126: 00°11′ S., 08°39′ E.; 2000–2400 hours, April 16, 1968; 1,080 m., surface temperature 28.8° C.; 1 specimen, 104 mm. SL. Sta. 132: 00°38′ N., 07°21′ E.; 1900–2400 hours, April 17, 1968; 2,664 m., surface temperature 29.6° C.; 3 specimens, 29.9 to 49.8 mm. SL. Sta. 138: 01°20′ N., 07°55′ E.; 2030–0230 hours, April 19–20, 1968; 2,400 m., surface temperature 28.6° C.; 13 specimens, 13.8 to 147 mm. SL. Sta. 152: 02°25′ N., 06°29′ E.; 2200–0200 hours, April 23–24, 1968; 1,520 m., surface temperature 28.9° C.; 1 specimen, 47.9 mm. SL. Sta. 158: 04°52′ N., 05°34′ E.; 0000–0215 hours, April 25, 1968; 240 m., surface temperature 28.8° C.; 16 specimens, 29.5 to 238 mm. SL.

All study material is cataloged in the fish collections of BCF Tropical Atlantic Biological Laboratory, Miami, Fla.

DEVELOPMENT AND GROWTH

My discussion of changes during development and growth concerns loss of larval characteristics, pigmentations, fin rays, and relations of measurements of various body parts.

LOSS OF LARVAL CHARACTERISTICS

Within the size range represented here, head spines are lost, scales undergo changes, caudal keels develop, and changes occur in the dorsal, anal, and pelvic fins.

Head Spines

In an earlier paper on the Atlantic sailfish (Gehringer, 1957), I reported pterotic and preopercular spines on a 101-mm. SL specimen. Voss

(1953) stated that these spines were not present on a 208-mm. SL specimen. In the present large series of western and eastern Atlantic sailfish, pterotic spines are present only as traces on some fish as short as 100 mm. SL, are present on all fish up to 150 mm. SL, and are absent on specimens longer than 150 mm. SL. Preopercular spines are present on all specimens but the largest, 216 to 238 mm. SL—they are probably lost at about this size.

Scales

Scale spines are first discernible on the dorsolateral surface of the body on sailfish about 30 mm. SL. Specimens about 50 mm. SL have spines on the cheeks and most of the body, except for the area on the side covered by the depressed pectoral fin and on the back along the anterior portion of the dorsal fin. Scales on the largest specimens, 216 to 238 mm. SL, are cycloid and differ from the illustration and description of scales on a 101-mm. fish (Gehringer, 1957) as follows: shape more elliptical than round, spine relatively shorter and weaker, and concentric ridges greater in number. On all specimens longer than 30 mm. SL the spine tips protrude through the skin and give a feeling of roughness.

Development of Caudal Keels

Two keels on each side, extending from the base of the caudal fin onto the caudal peduncle, develop at about 84 to 92 mm. SL. The smallest sailfish with keels is 83.8 mm. SL, and the largest without keels is 91.4 mm. SL. The upper keel apparently develops first as it is the only one present on the few fish 85 to 90 mm. SL with but one keel.

Development of Dorsal and Anal Fins

As discussed under definitions of terms, the last six or seven rays of both dorsal and anal fins form distinct second fins in the adult. The dorsal and the anal fins on all specimens in the present series are single and continuous. On larger specimens the few anal rays immediately forward of the terminal six or seven rays are small and weak; these rays are weak and overgrown with skin in the adult. Dorsal rays in this relative position are not so weak, but are less robust than those immediately ahead or behind which do not become overgrown with skin. On most specimens over 80 mm. SL, the distal portion of the anal ray immediately ahead of the terminal six or seven rays is depressed, overgrown with tissue, and nearly adnate to the base of the succeeding ray.

Pelvic Fin

The first and second rays of the pelvic fin, which in the adult are fused into one robust bony ray, are nearly fused on the largest specimens, 216 to 238 mm. SL—the first ray appears as a short, triangular-shaped segment of the leading edge of the second ray. The third ray is separate and distinct at all sizes.

PIGMENTATION

Pigmentation of Atlantic sailfish larvae, juveniles, and adults has been described by several authors, including Voss (1953), Gehringer (1957), Robins and de Sylva (1963), and de Sylva (1963). My comments here on pigmentation of fins and body bars supplement these accounts for specimens 26 to 238 mm. SL and apply to both eastern and western Atlantic specimens.

Fins

The pectoral fins are clear except for a few melanophores at the bases of the first few rays on the largest specimens.

The pelvic fins are lemon-yellow with a few melanophores on the membrane between the second and third rays on sailfish over 155 mm. SL.

Pigment on the anterior portion of the dorsal fin is uniformly dusky to dark except for two to several large, dark spots scattered in a nonuniform pattern over the fin (figs. 1–5). On some fish the first few dorsal rays are less densely pigmented than the rest of the fin. Pigment extends posteriorly on the fin to the 34th to 40th ray—the last few rays of the anterior portion have no pigment. The posterior portion (terminal six or seven rays) of the fin is clear except for pigment on the bases of the fin rays and fin membrane on specimens longer than about 135 mm. SL.

The anal fin is clear on all specimens.

The smallest sailfish with pigment on the caudal fin is 44.2 mm. SL; the largest without pigment on the caudal fin is 51.7 mm. SL. A group of a few melanophores is present on the lower lobe of the caudal fin of a series of fish 44.2 to 60.0 mm. SL, and a similar group of melanophores is also on the upper lobe of a series of specimens 50.0 to 64.0 mm. SL. The melanophores are coalesced into blotches on several fish 53.2 to 67.0 mm. SL, and, though

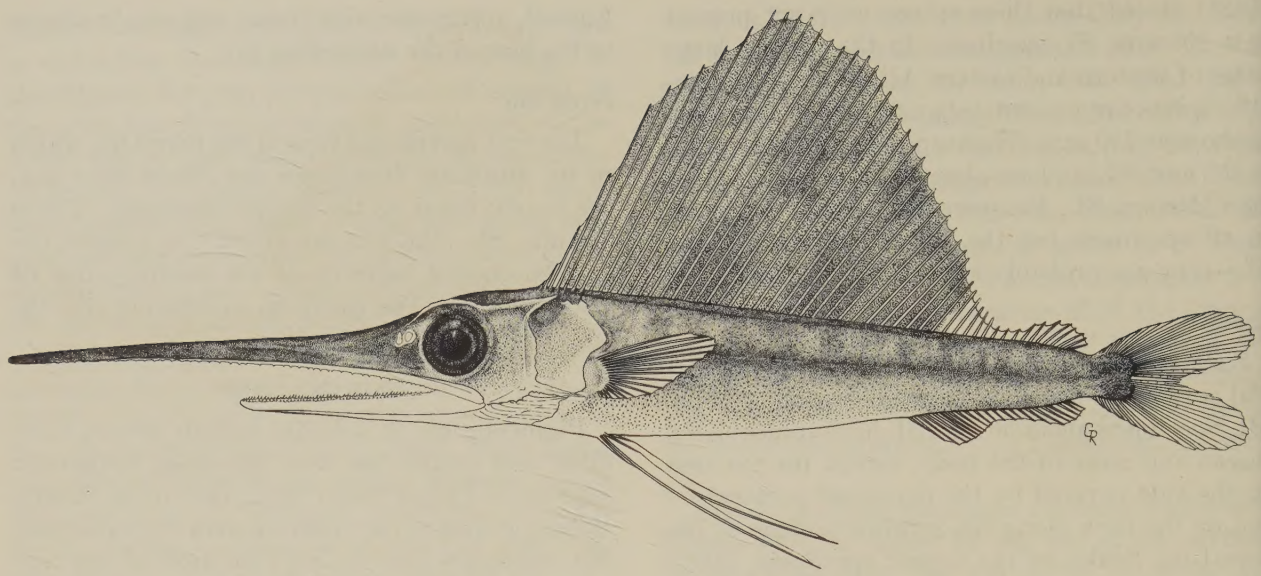

FIGURE 1.—Juvenile sailfish, 37.1 mm. standard length, *Silver Bay* Sta. 2268.

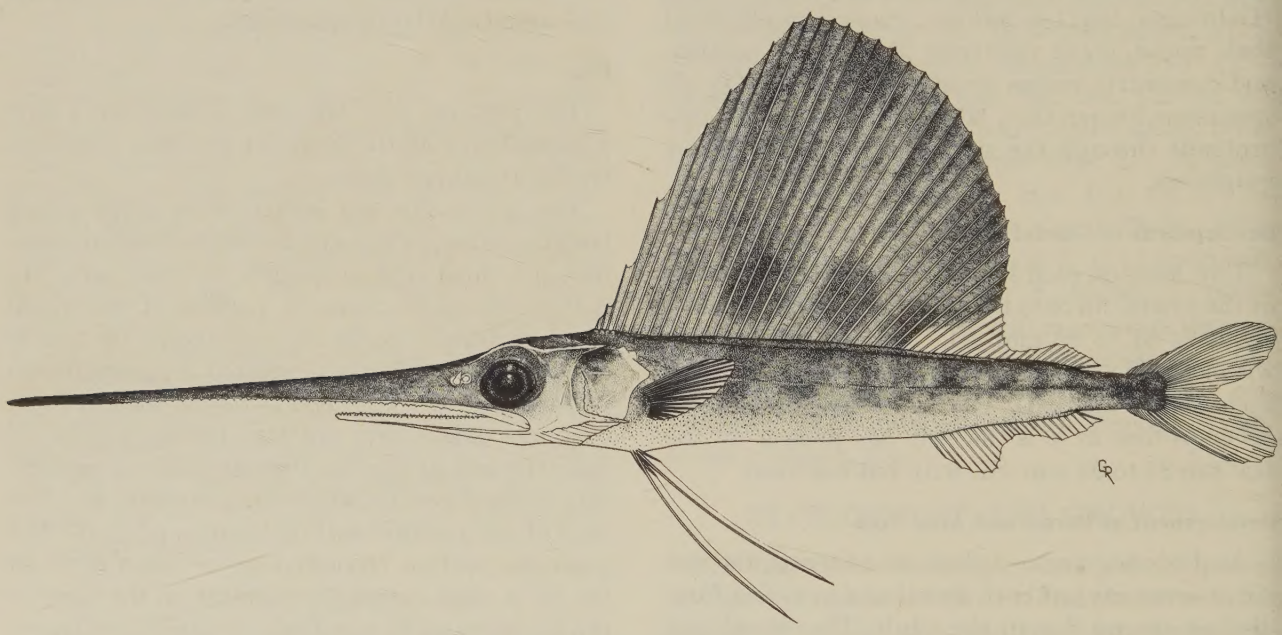

FIGURE 2.—Juvenile sailfish, 55.1 mm. standard length, *Silver Bay* Sta. 2268.

larger and covering more of the fin lobes, the blotches are distinct on a series of specimens 101 to 119 mm. SL. On a 190-mm. SL sailfish, pigment spreading posteriorly from the base of the fin joins that spreading anteriorly on the lobes and covers the fin except for the distal half of the middle seven caudal rays and ray membrane, which remain clear. On the largest specimens, 216 to 238 mm. SL, the clear area of the middle part of the caudal fin is reduced to the distal third of the middle six caudal rays and ray membrane, the lobes of the caudal fin are dusky, and the tissue covering the bases of the rays is densely pigmented.

Body Bars

Pigment on the sides of the body is concentrated in five to seven bars on fish of about 30 mm. SL. Bars are not discernible on smaller specimens. Sail-

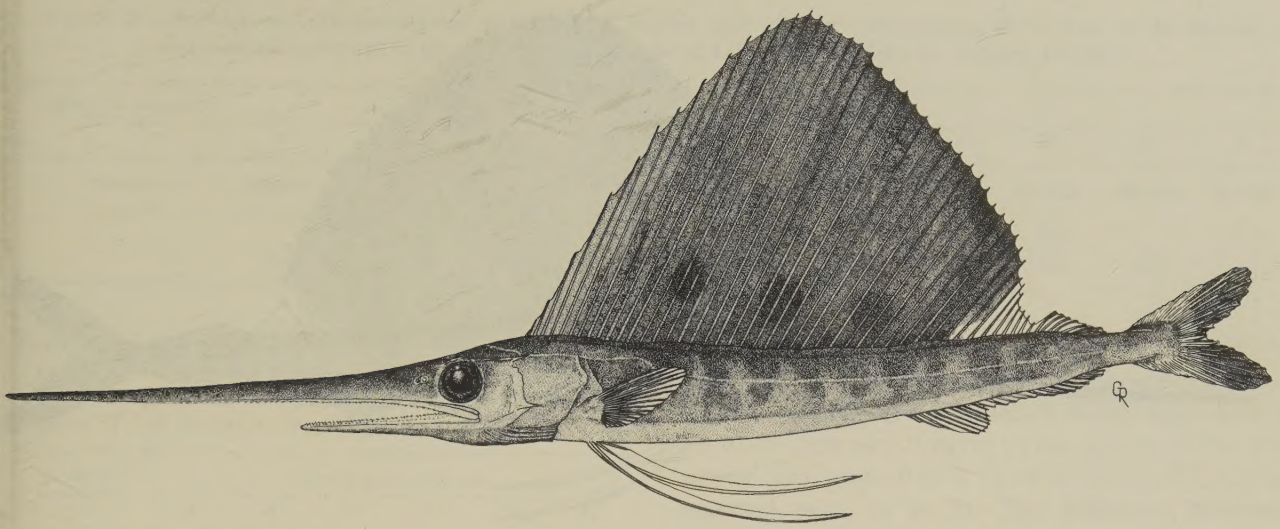

FIGURE 3.—Juvenile sailfish, 98.9 mm. standard length, *Silver Bay* Sta. 2201.

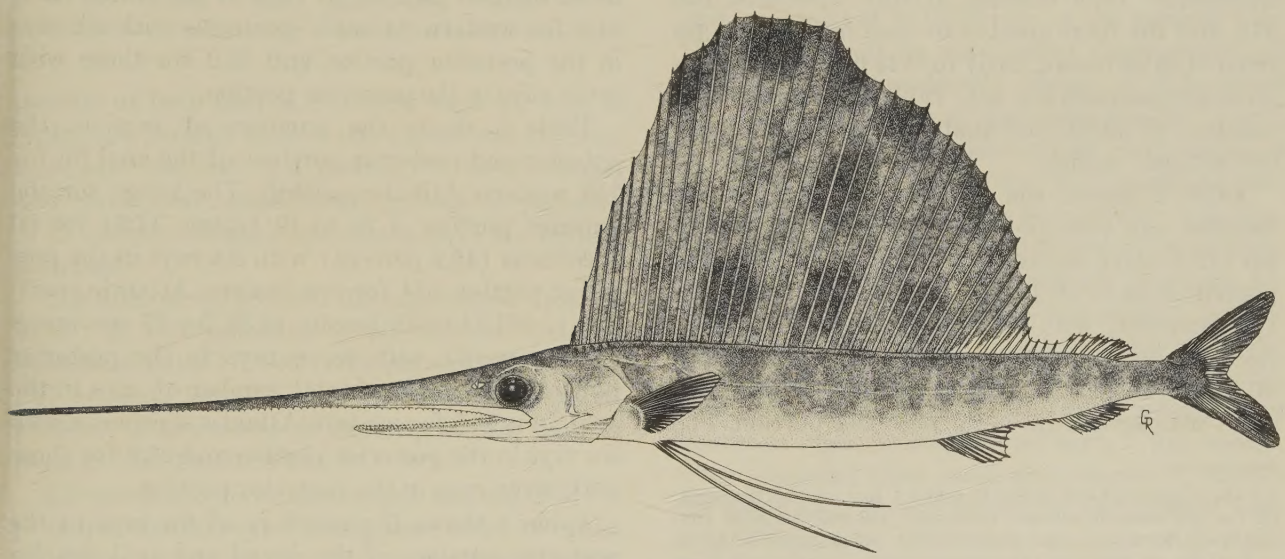

FIGURE 4.—Juvenile sailfish, 155 mm. standard length, *Silver Bay* Sta. 2139.

fish about 100 mm. SL have 7 to 12 bars, and the few specimens between 150 and 200 mm. SL have 12 to 14 bars. The largest western Atlantic specimen, 216 mm. SL, has 22 bars. Throughout the size range examined here the bars are distinct on some fish but indistinct on others and arranged in pairs on some specimens but not on others.

FIN RAYS

The numbers of fin rays for western and eastern Atlantic specimens with undamaged fins are within the adult complements. I prepared tables of numbers of fin rays for western Atlantic specimens only. The fins of a number of eastern Atlantic specimens were damaged, and too few counts are available to make useful tables. The numbers of fin rays for eastern Atlantic specimens are within the ranges for western Atlantic specimens, except for a few differences which are mentioned in the discussions.

The total number of dorsal fin rays ranges from 47 to 56 (mean, 51.6) for 142 western Atlantic

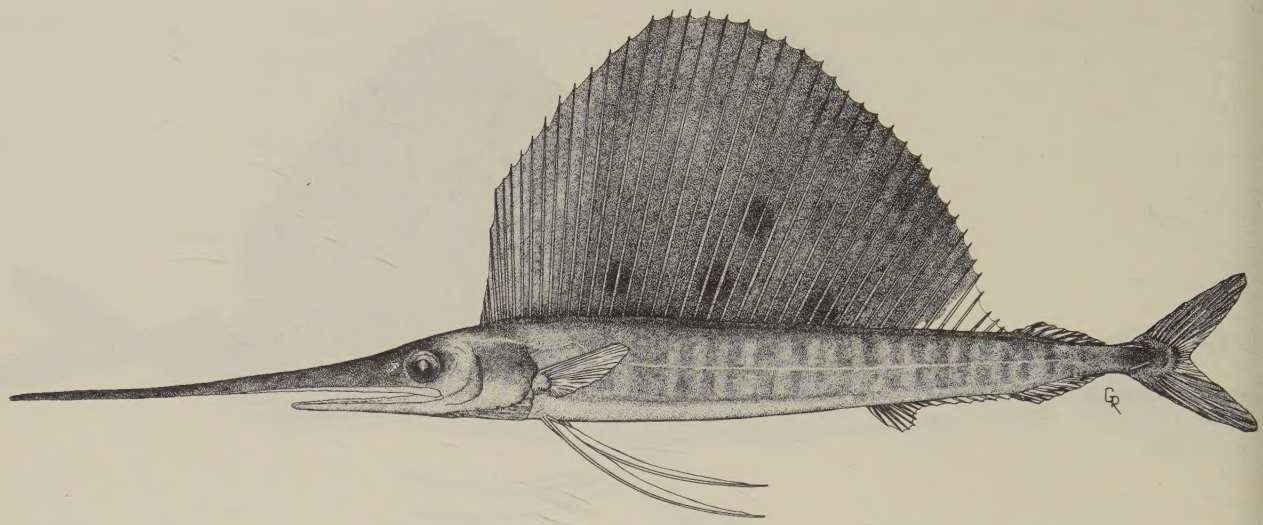

FIGURE 5.—Juvenile sailfish, 216 mm. standard length, *Silver Bay* Sta. 2172.

specimens[3] (one eastern Atlantic specimen has 57), and the total number of anal fin rays ranges from 21 to 25 (mean, 23.6) for 143 fish (one eastern Atlantic specimen has 20). Table 1 shows the total numbers of dorsal and anal fin rays for 139 western Atlantic sailfish.

Table 2 shows the numbers of rays in the anterior and posterior portions of the dorsal fin for 142 western sailfish. The range for the anterior portion is 43 to 50 (mean, 45.0) for 46 specimens (32.4 percent) with six rays in the posterior portion (51 for one eastern Atlantic specimen), and 40 to 49 (mean, 45.0) for 96 specimens (67.6 percent) with seven rays in the posterior portion. The mean of total number of rays in the dorsal fin is 51.0 for western Atlantic specimens with six rays in the posterior portion and 52.0 for those with seven rays in the posterior portion.

Table 3 shows the numbers of rays in the anterior and posterior portions of the anal fin for 143 western Atlantic sailfish. The range for the anterior portion is 15 to 19 (mean, 17.3) for 66 specimens (46.2 percent) with six rays in the posterior portion (14 for one eastern Atlantic specimen), and 14 to 18 (mean, 16.8) for 77 specimens (53.8 percent) with seven rays in the posterior portion. The mean of total number of rays in the anal fin is 23.3 for western Atlantic specimens with six rays in the posterior portion and 23.8 for those with seven rays in the posterior portion.

Table 4 shows the numbers of fin rays in the posterior portions of the dorsal and anal fins for the western Atlantic sailfish. Nearly half (46.8 percent) of 141 specimens have seven rays in this

[3] The numbers of fish shown in tables 1 to 4 are not the same. Of the 154 western Atlantic specimens, 139 had complete (undamaged) dorsal and anal fins, the rest had a complete dorsal or anal fin, or complete anterior or posterior portions of these fins. To take advantage of the greatest number of specimens for correlations, I used all sailfish with counts for desired fins or portions of fins. The same fish were not always involved.

TABLE 1.—*Number and (in parentheses) percentage of sailfish with different combinations of dorsal and anal fin rays, in a series of 139 specimens from the western Atlantic*

Anal fin rays	Dorsal fin rays									
	47	48	49	50	51	52	53	54	55	56
Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
21				1 (0.7)		1 (0.7)				
22			4 (2.9)	3 (2.2)	4 (2.9)	1 (0.7)				
23		1 (0.7)	7 (5.0)	9 (6.5)	9 (6.5)	10 (7.2)	8 (5.8)	3 (2.2)	1 (0.7)	
24	1 (0.7)		3 (2.2)	7 (5.0)	14 (10.1)	11 (7.9)	9 (6.5)	8 (5.8)	2 (1.4)	1 (0.7)
25			2 (1.4)	1 (0.7)	1 (0.7)	5 (3.6)	5 (3.6)	6 (4.3)		1 (0.7)

TABLE 2.—*Number and (in parentheses) percentage of sailfish with different combinations of fin rays in the anterior and posterior portions of the dorsal fin, in a series of 142 specimens from the western Atlantic*

Posterior portion fin rays	Anterior portion fin rays										
	40	41	42	43	44	45	46	47	48	49	50
Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
6	-----	-----	-----	10 (7.0)	9 (6.3)	11 (7.7)	10 (7.0)	2 (1.4)	3 (2.1)	--- -----	1 (0.7)
7	1 (0.7)	2 (1.4)	5 (3.5)	11 (7.7)	18 (12.7)	19 (13.4)	21 (14.8)	15 (10.6)	3 (2.1)	1 (0.7)	-----

TABLE 3.—*Number and (in parentheses) percentage of sailfish with different combinations of fin rays in the anterior and posterior portions of the anal fin, in a series of 143 specimens from the western Atlantic*

Posterior portion fin rays	Anterior portion fin rays					
	14	15	16	17	18	19
Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
6	-----	1 (0.7)	11 (7.7)	27 (18.9)	23 (16.1)	4 (2.8)
7	1 (0.7)	4 (2.8)	20 (14.0)	33 (23.1)	19 (13.3)	-----

portion of both fins, 24.8 percent have six rays in each, 20.6 percent have seven dorsal and six anal rays, and the rest (7.8 percent) have six dorsal and seven anal rays. Twenty (about 75 percent) of 27 eastern Atlantic specimens have six rays in both fins.

The number of pectoral fin rays ranges from 17 to 20; 10 (6.9 percent) of 145 western Atlantic specimens have 17, 126 (86.9 percent) have 18, 8 (5.5 percent) have 19, and 1 (0.7 percent) has 20. Fifteen of 28 eastern Atlantic specimens have 17 rays, 12 have 18, and 1 has 19.

All specimens have nine upper and eight lower principal caudal rays. Counts were 11 or 12 upper and lower secondary caudal rays for several specimens (40–216 mm. SL) which were cleared and stained or X-rayed.

TABLE 4.—*Number and (in parentheses) percentage of sailfish with different combinations of fin rays in the posterior portions of the dorsal and anal fins, in a series of 141 specimens from the western Atlantic*

Anal fin rays	Dorsal fin rays	
	6	7
Number	*Number*	*Number*
6	35 (24.8)	29 (20.6)
7	11 (7.8)	66 (46.8)

Fin-ray counts given by Robins and de Sylva (1963) for adult *Istiophorus platypterus* are: dorsal spines, 40 to 49; second dorsal rays, 6 to 8 (1 of 59 fish had 8 rays); anal spines, 12 to 17; second anal rays, 6 to 8 (1 of 59 fish had 8 rays), pectoral rays, 18 to 21. The difference between their range of 40 to 49 dorsal spines and my range of 43 to 50 rays in the anterior portion of the dorsal fin and their range of 12 to 17 anal spines and my range of 14 to 19 rays in the anterior portion of the anal fin may reflect degeneration of several rays immediately ahead of the second dorsal and anal fins and their overgrowth by skin in the adult. A comparison of the percentages of my fish with six and seven rays in the posterior portions of the dorsal and anal fins with the information given by Robins and de Sylva is interesting. Roughly, one-third of their and my (western Atlantic) fish (32.2 percent and 32.4 percent, respectively) had six second dorsal fin rays and two-thirds (66.1 percent and 67.6 percent, respectively) had seven second dorsal fin rays (they recorded one fish with eight second dorsal rays, I had none). They recorded these same percentages of sailfish for numbers of second anal rays; 32.2 percent with six, 66.1 percent with seven, and one with eight rays. My counts are different; they show 46.2 percent with six rays, 53.8 percent with seven, and none with 8 in the posterior portion of the anal fin.

REGRESSIONS OF BODY PARTS ON TRUNK LENGTH

Comparisons of the changes in various body parts of fishes during development have been variously based on standard, fork, or total length. The snout and caudal rays are so frequently damaged in the billfishes that measurements involving one or both of these parts may be inaccurate. Body length, recommended by Rivas (1956) as the preferred base length for billfishes, is the distance between the tip of the mandible and the

tips of the middle caudal fin rays. This measurement involves fin rays that are fragile and frequently damaged on small specimens. The base length that I selected for my comparisons is the trunk length, defined by de Sylva (1957) as the distance between the posterior margin of the orbit and the anterior insertion of the caudal keels. This length involves neither the snout nor the caudal rays.[4]

[4] See definition for trunk length in section on methods and data for determination of posterior point for this measurement of sailfish without caudal keels.

Initially, individual measurements of selected body parts of the western Atlantic sailfish were plotted against trunk length on arithmetic paper (figs. 6–12). The distribution of the data suggested that the relatively fewer specimens with trunk length greater than 60 mm. should be treated separately. Two regression lines were calculated—one for those with trunk length less than 62 mm. and one for longer specimens. The regression equation is $Y=a+bX$ (table 5). Inspection of the graphs with the calculated regression lines added suggests that the location of point of inflection varies some-

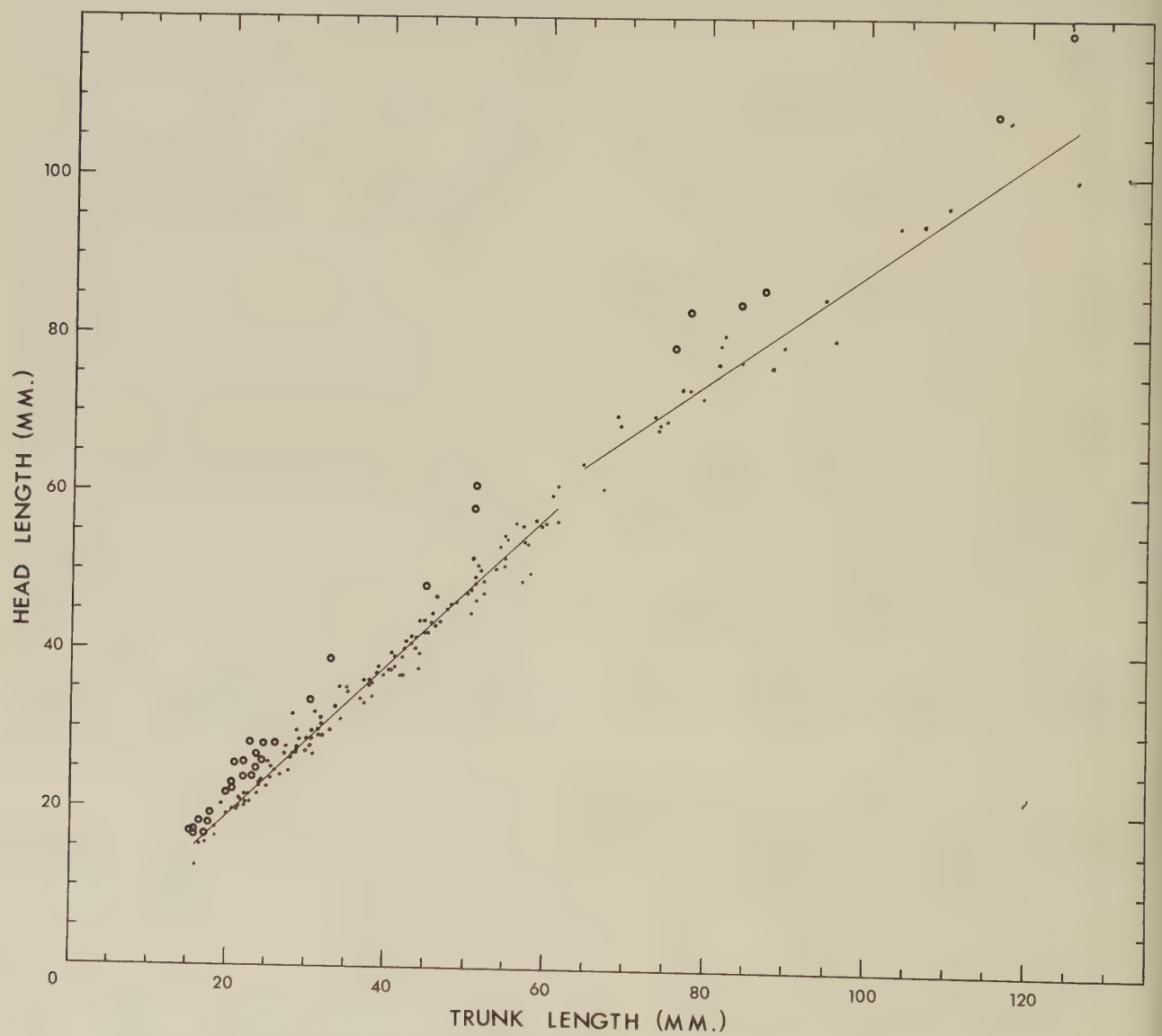

FIGURE 6.—Relation of head length to trunk length in sailfish. Small dots represent western Atlantic specimens; open circles, eastern Atlantic specimens. Regression lines represent western Atlantic data only.

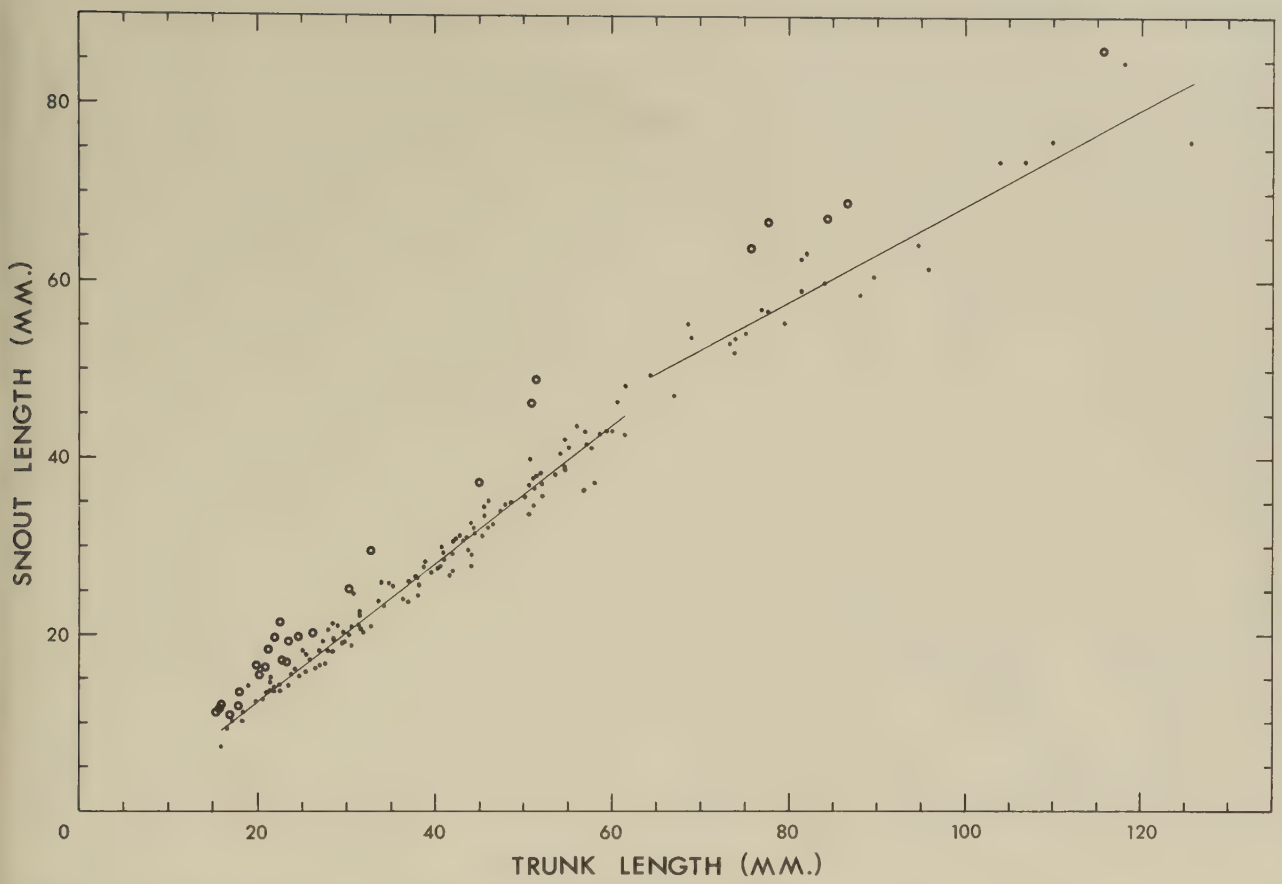

FIGURE 7.—Relation of snout length to trunk length in sailfish. Small dots represent western Atlantic specimens; open circles, eastern Atlantic specimens. Regression lines represent western Atlantic data only.

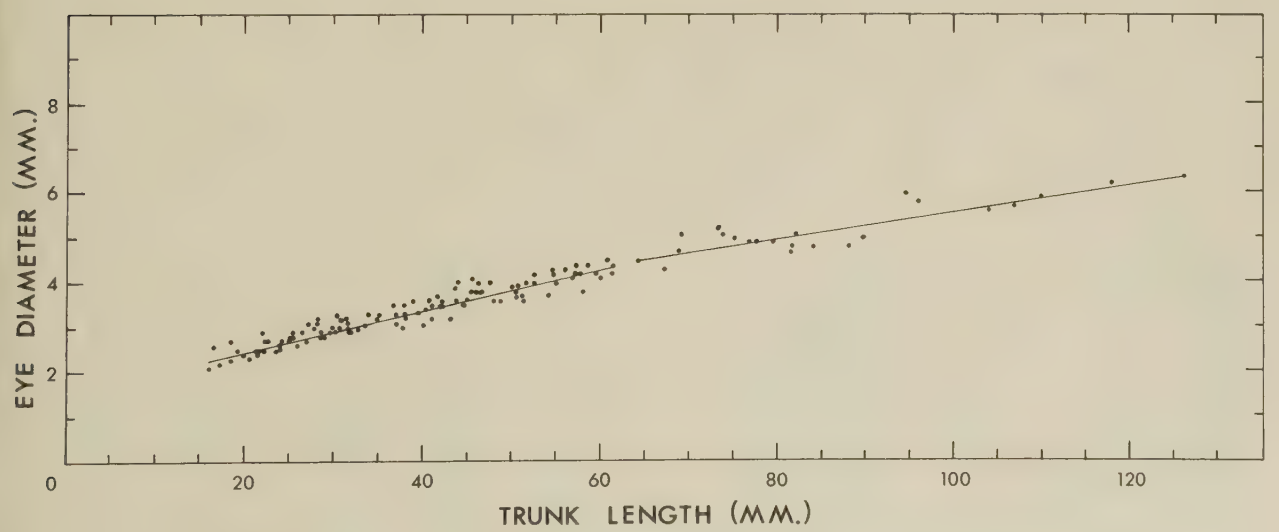

FIGURE 8.—Relation of eye diameter to trunk length in sailfish from the western Atlantic.

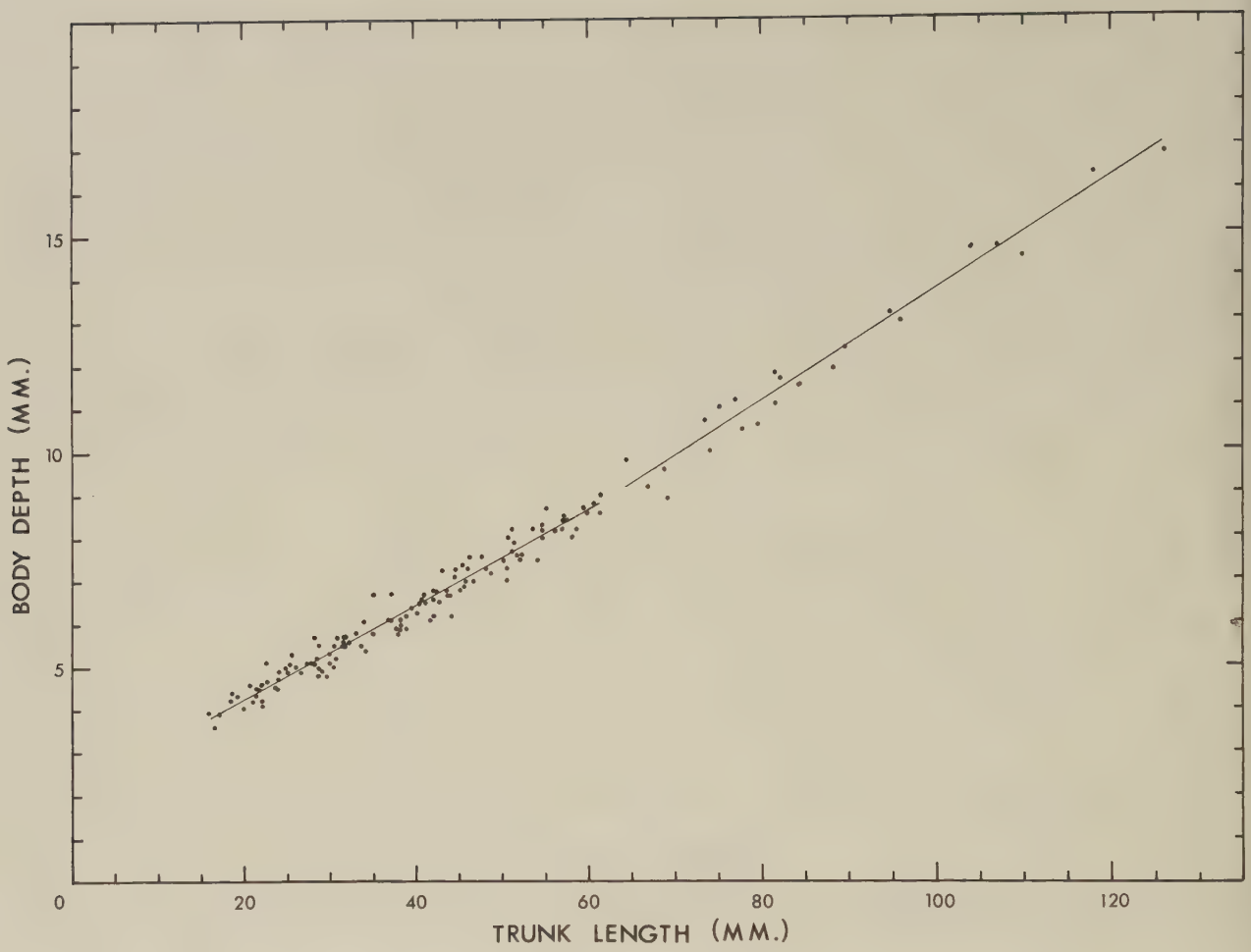

FIGURE 9.—Relation of body depth to trunk length in sailfish from the western Atlantic.

TABLE 5.—*Statistics describing regressions of body parts on trunk length, or body length, for sailfish from the western Atlantic*

[$\bar{x}$, mean of values of X; $\bar{y}$, mean of values of Y; N, number of specimens; b, slope of regression line; a, Y-intercept of regression line; Sy.x, standard deviation from regression (standard error of estimate)]

Independent variable X and specimen size [1]	Dependent variable Y	$\bar{x}$	$\bar{y}$	N	b	a	Sy.x
Trunk length:							
Small	Head length	37.92	35.87	130	0.942	0.142	1.610
Large	do	86.04	78.32	24	.694	18.592	3.263
Small	Snout length	37.92	26.37	130	.782	−3.279	1.517
Large	do	86.04	60.94	24	.538	14.619	3.209
Small	Eye diameter	37.65	3.30	121	.045	1.626	.111
Large	do	86.56	5.19	23	.029	2.677	.273
Small	Body depth	37.92	6.20	130	.109	2.067	.273
Large	do	86.04	11.92	24	.127	.997	.367
Small	Pectoral fin length	37.92	5.82	127	.109	1.678	.372
Large	do	83.85	9.99	18	.078	3.421	.444
Small	Pelvic fin length	37.26	15.04	124	.405	−.042	.937
Large	do	83.85	33.40	18	.348	4.237	1.499
Small	Pelvic fin-anal fin	37.92	18.64	130	.486	.227	.510
Large	do	86.04	41.32	24	.477	.282	.923
Body length:							
Small	Trunk length	52.87	37.58	124	.786	−3.961	.981
Large	do	114.38	85.79	22	.796	−5.204	1.377

[1] Small, 16.0–61.5 mm. trunk length; large, 64.5–126 mm. trunk length.

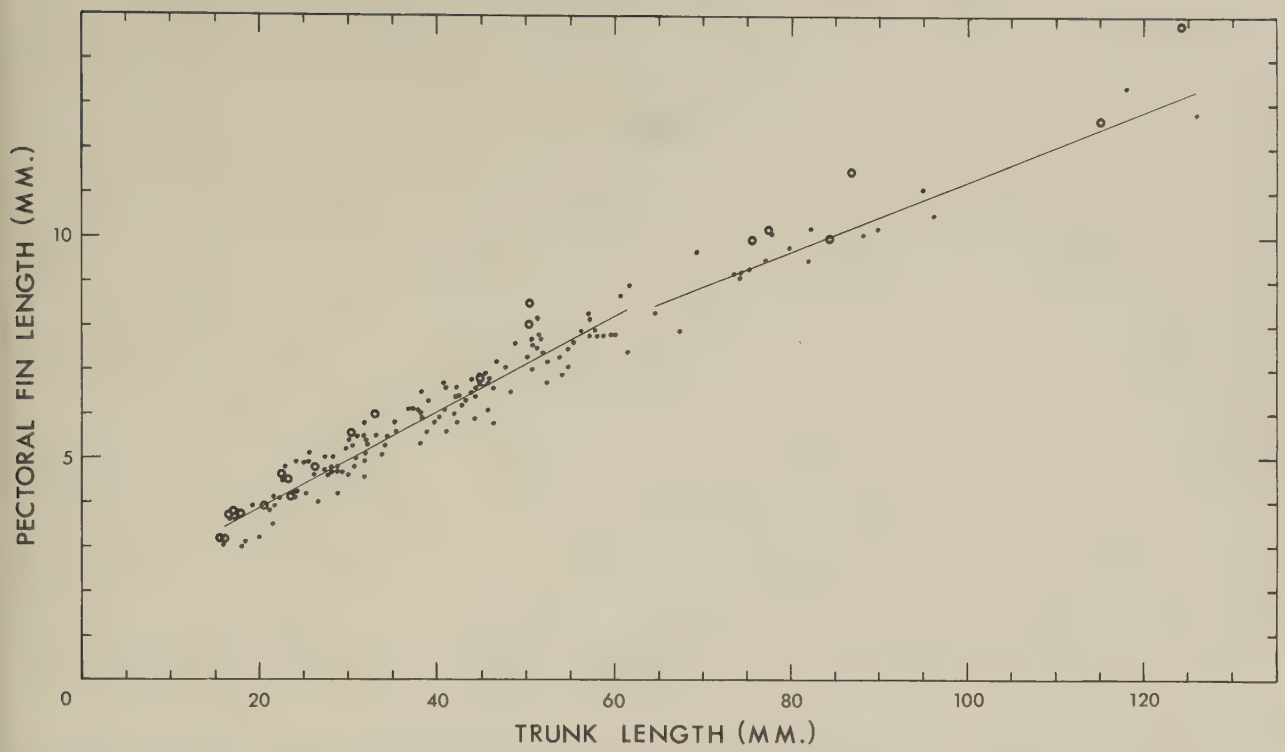

FIGURE 10.—Relation of pectoral fin length to trunk length in sailfish. Small dots represent western Atlantic specimens; open circles, eastern Atlantic specimens. Regression lines represent western Atlantic specimens only.

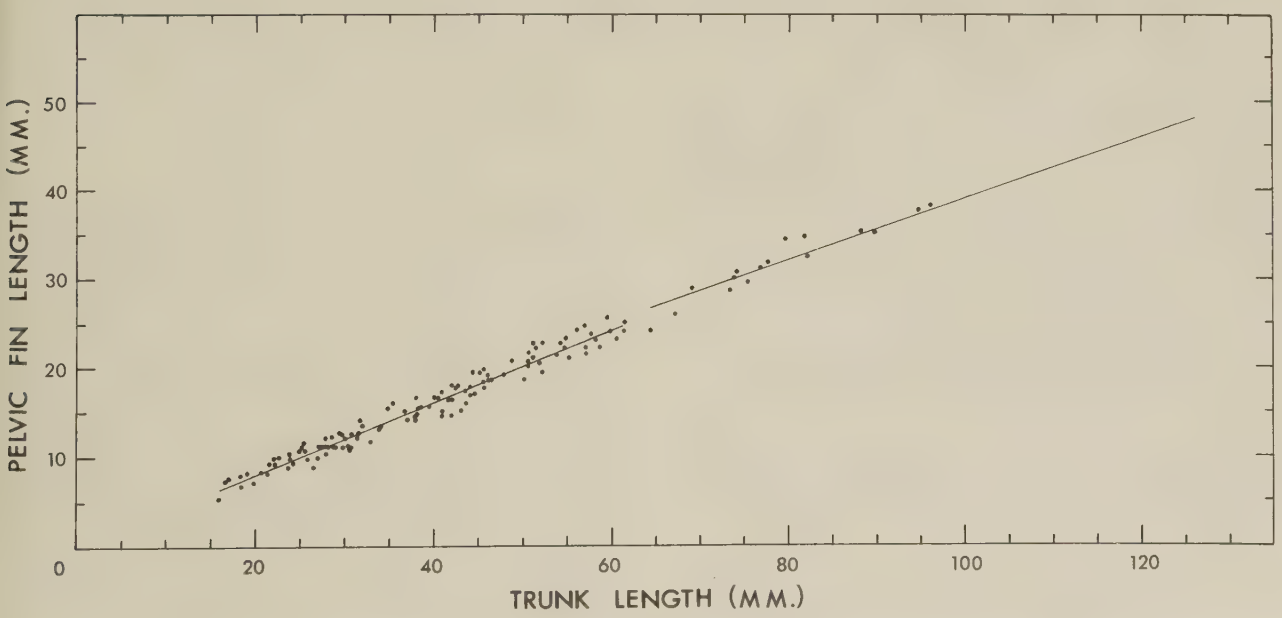

FIGURE 11.—Relation of pelvic fin length to trunk length in sailfish from the western Atlantic.

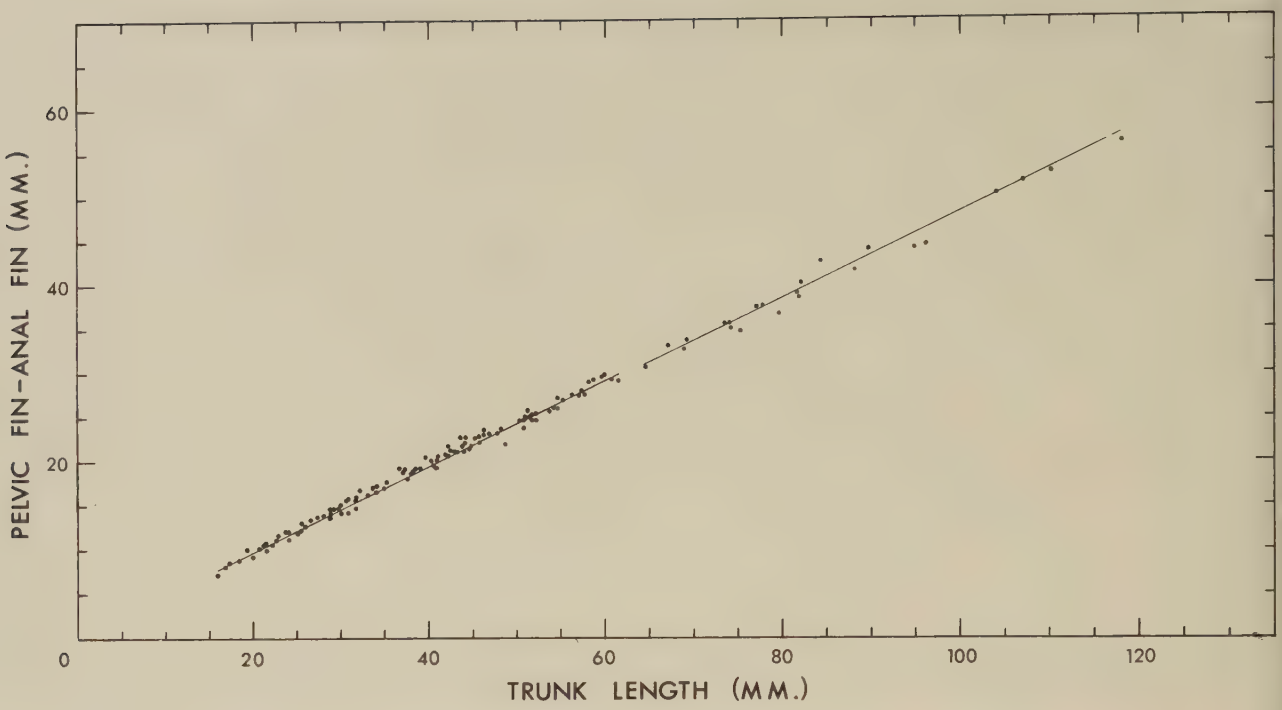

FIGURE 12.—Relation of the distance pelvic fin-anal fin to trunk length in sailfish from the western Atlantic.

what with body part and that some parts have little or no inflection. Figure 13, which illustrates the regression of trunk length on body length, is included to show that this relation is rectilinear throughout the size range; the calculated regression line for specimens with trunk length greater than 62 mm. has the same slope (b) and is merely an extension of that for smaller fish.

Subsequent to preparation of plots of data and calculation of regression lines for western Atlantic sailfish, I obtained measurements from 34 eastern Atlantic fish and plotted them on graphs. The data from the eastern Atlantic are too meager, however, for making calculations of regressions—the number of specimens is too small and the size distribution is poor. Because the greater numbers of western Atlantic specimens might possibly hide differences between the two groups if the data were combined, I plotted them separately on the same graph, distinguishing the two groups. I shall limit my comments to differences this simple comparison suggests.

The individual plots of data for eastern Atlantic sailfish generally lie within the ranges for fish from the western Atlantic for eye diameter, body depth, pelvic fin length, and distance from pelvic fin to anal fin; these data are, therefore, not shown on the figures showing these relations (figs. 8, 9, 11, and 12, respectively). Measurements of snout length, head length, and pectoral fin length, however, generally lie higher on the graphs for fish from the eastern Atlantic than for those from the western Atlantic (figs. 6, 7, and 10). The longer head (fig. 6) is attributable to the generally longer snout (fig. 7). The pectoral fin is also generally longer in eastern Atlantic sailfish (fig. 10).

ACKNOWLEDGMENTS

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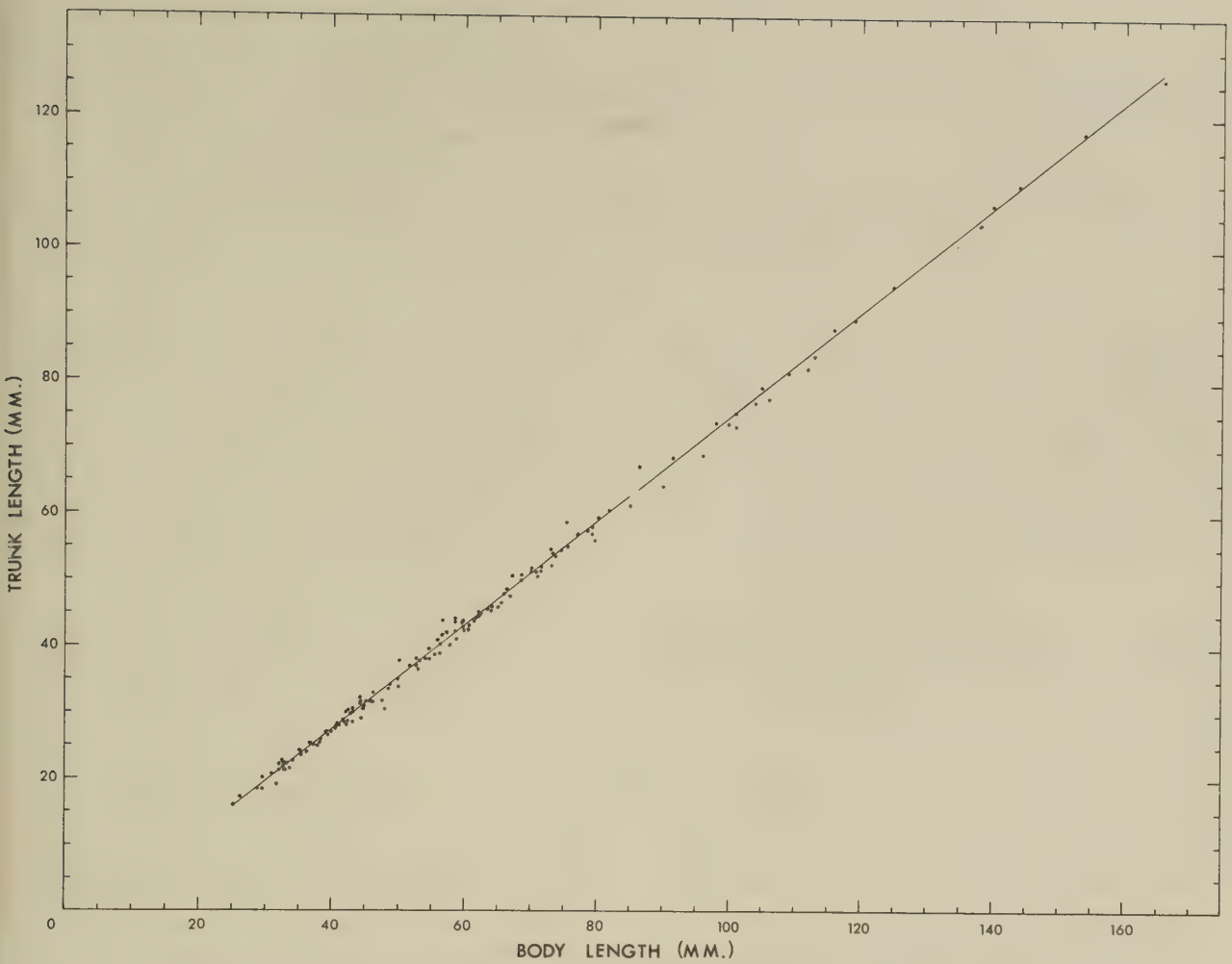

FIGURE 13.—Relation of trunk length to body length in sailfish from the western Atlantic.

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MOLLUSKS AND BENTHIC ENVIRONMENTS IN HILLSBOROUGH BAY, FLORIDA[1]

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ABSTRACT

Analysis of benthic mollusks and sediments at 45 stations showed that the diversity and abundance of mollusks was affected by bottom conditions which were influenced in varying degrees by domestic and industrial pollution and dredging. Nineteen stations had no living mollusks, 18 stations had one or more of the four mollusk species that were predominant, and 8 stations had mollusks well represented by numerous species and large numbers of individuals. Stations with no living mollusks were termed unhealthy, and others were designated marginal or healthy on the basis of the mollusks present. From station data, isopleths connecting similar areas indicated that 42 percent of the bay bottom was unhealthy, 36 percent marginal, and 22 percent healthy. Infrequent occurrence of the American oyster (*Crassostrea virginica*) further suggests that the major portion of Hillsborough Bay was seriously contaminated. An appendix has a checklist of the 64 species of mollusks collected in the bay.

This report treats the relation of diversity and abundance of mollusks to bottom conditions in Hillsborough Bay, Fla., where dredging and pollution from domestic and industrial sources now control the ecology. The data are from benthic and hydrological surveys by the Bureau of Commercial Fisheries Biological Laboratory, St. Petersburg Beach, Fla., during August and September 1963.

The problem of pollution in coastal waters has stimulated research to establish environmental quality criteria based on physical, chemical, and biological components of marine and brackish water communities. Mollusks are useful in such studies because the group is well described taxonomically and contains species that vary greatly in habitat selection, mode of feeding, and tolerance to environmental change. Furthermore, most mollusks are sedentary as adults and the remains of their shells provide a semipermanent record of their occupancy.

The ecology of mollusks in natural waters has been studied by a number of authors. Previous studies on the ecology of mollusks in natural and polluted waters of the southeastern United States provided a basis for the interpretation of collections from Hillsborough Bay. Reports on mollusk assemblages in unpolluted estuaries included work by Ladd (1953), Parker (1960), and Brett (1963). Within the same geographic area, studies of mollusks in polluted estuaries include work on the ecological effects of petroleum wastes (Mackin and Hopkins, 1961), pesticides (Butler, 1966), siltation and dredging (Mackin, 1961), channelization (Chambers and Sparks, 1959), and domestic sewage (McNulty, 1966). The work by McNulty, and an earlier series of studies with collaborators, represent a comprehensive study over a period of 11 years in Biscayne Bay, Fla., before and after pollution abatement.

ECOLOGICAL FEATURES OF HILLSBOROUGH BAY

Hillsborough Bay lies in the upper part of Tampa Bay, east of Interbay Peninsula and north of a line between Gadsden Point and Newman Branch (fig. 1). The 56-km. shoreline encompasses a water area of about 10,360 ha. Forty percent of this area is 1.8 m. or less, and except for dredged ship channels up to 10.5 m. deep, the greatest depth in the bay is about 5.4 m. Tidal range is normally 0.9 m. or less, and maximum tidal current is under 51 cm./second (1 knot)—see Olson and Morrill (1955) and Taylor and Saloman (1969). Portions of the bay around Davis Island, Seddon Island, McKay Bay, and Port Sutton have been dredged for fill material or deepened for shipping (fig. 1). Other dredging in the bay centers around oyster shell deposits which are used for the construction industry (Dawson, 1953). These deposits are extensive and show that the American oyster, *Crassostrea virginica*, once

[1] Contribution No. 56, Bureau of Commercial Fisheries Biological Laboratory, St. Petersburg Beach, Fla. 33706.

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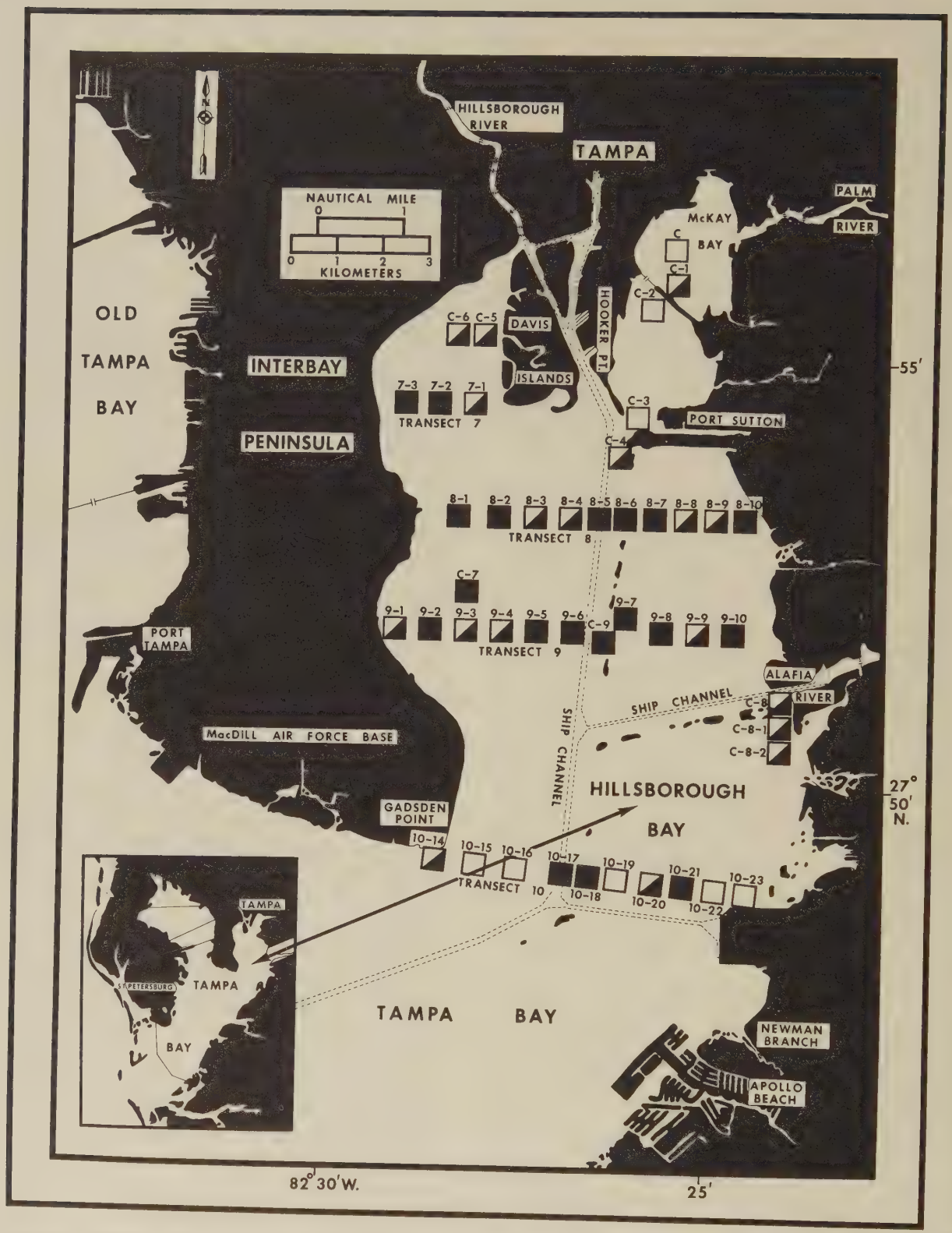

FIGURE 1.—Tampa Bay and Hillsborough Bay showing channels, survey transects, collecting stations, and environmental conditions at each station—healthy stations (unshaded); marginal stations (half-shaded); unhealthy stations (shaded)—August and September 1963.

flourished in Hillsborough Bay as it does today along most of the Gulf Coast between Cape Sable and the Rio Grande (Butler, 1954). The annual mean and range of salinity (22.20 and 12.65–27.84 p.p.t.), water temperature (24.96° and 11.65°–34.00° C.), and other hydrological features of the bay have been reported by Saloman and Taylor (1968).

In addition to considerable physical alteration of the bay, water chemistry and resident biota have changed decidedly as a result of domestic and industrial sewage. The principal identified pollutants are compounds of phosphorus and nitrogen, and highly organic suspended solids. Regional sanitation plants provide only primary sewage treatment for 120,000 m.^{3}/day (30 m.g.d.—million gallons per day) and serve a population of about 300,000. The treated effluent carries more than 50 percent of the suspended solids present before treatment and adds an enormous load of phosphorus and nitrogen.[2] The solids are deposited as sludge, and phosphorus and nitrogen are available as nutrients for plants and animals. The phosphate industry provides additional sediment and phosphorus, and natural land drainage provides substantial amounts of phosphorus, nitrogen, iron, copper, and organic compounds (Odum, 1953; Dragovich and May, 1962; Dragovich, Kelly, and Goodell, 1968). Dragovich et al. (1968) estimated that the Hillsborough and Alafia Rivers together add 557 metric tons of phosphorus to the bay each year. In the bay the annual mean concentration of total phosphorus is 19.38 μg.at./liter, and the total nitrogen (Kjeldahl) is 80.17 μg.at./liter. Comparative figures for Tampa Bay entrance (P=14.39; N=45.08 μg.at./liter) and the nearshore Gulf of Mexico (P=3.6; N=23.4 μg.at./liter) give some idea of the extraordinary mineral enrichment that exists in Hillsborough Bay (Saloman and Taylor, 1968). In Biscayne Bay, Fla., McNulty, Reynolds, and Miller (1959) and McNulty (1966) found that domestic sewage adversely affected the biotic environment. There, daily discharge of 120,000 to 200,000 m.^{3}/day (30-50 m.g.d.) of raw sewage raised the average concentration of total phosphorus to 3 μg.at./liter or about one-sixth of the concentration now in Hillsborough Bay.

Enrichment of Hillsborough Bay by phosphorus and nitrogen causes excessive growth of phytoplankton and filamentous algae (Dragovich, Kelly, and Kelly, 1965). The heavy growth of algae and the phytoplankton blooms cause marked fluctuations in dissolved oxygen. In periods of photosynthetic activity, oxygen concentrations have exceeded 8 ml./liter but at other times, BOD (biochemical oxygen demand) may reduce dissolved oxygen to 1 ml./liter or less at the bottom (Saloman, Finucane, and Kelly, 1964; Saloman and Taylor, 1968; FWPCA, personal communication[3]).

Other consequences of pollution in Hillsborough Bay include high water turbidity (annual average, 19.19 Jackson Turbidity Units), low light transmission (annual average, 30.3 percent of incident radiation at 60 cm. below the water surface), and very little growth of marine grasses (Taylor and Saloman, 1966; Saloman and Taylor, 1968; and Taylor and Saloman, 1969). In their comparative study of macrofauna in major geographic areas of Tampa Bay, Sykes and Finucane (1966) provided further biological evidence of pollution in the bay. From quantitative sampling, their work showed that catches of fish and crustaceans were lower in Hillsborough Bay than in any other region of the estuary. The greatest catches came from Old Tampa Bay where environmental conditions differ from those in Hillsborough Bay mainly in terms of fewer and smaller sources of pollution, lower turbidity, lower nitrogen concentration, higher dissolved oxygen at the bottom, more sandy sediments, a more natural shoreline, and extensive beds of sea grasses.

PROCEDURES

We sampled mollusks together with bottom vegetation and sediments with a bucket dredge and rigid-frame net at 45 stations between August 13 and September 5, 1963 (fig. 1). The dredge dug 5 cm. into the bottom and had a capacity of 15 liters. It filled with sediment after covering an area of about 30 by 100 cm. The net skimmed the bottom and had an opening of 30.5 by 91.4 cm. It was hung with square-mesh netting with openings of 3.2 mm. (Taylor, 1965). At intertidal stations, the bottom was sampled by shovel and the

[2] Hillsborough County Health Department, Tampa, Fla. 33601, personal communication, 1969.

[3] Federal Water Pollution Control Administration, Tampa-Hillsborough Bay Project, Tampa, Fla. 33605, 1968.

net was pulled by hand. One dredge haul, or a nearly equivalent volume of sediment collected by shovel, and one 2-minute net haul were taken at each station. We collected water samples at each station with a Van Dorn bottle for determination of temperature, salinity, and pH. Water depth was measured by handline.

We removed the mollusks from bottom samples by sieving sediment and bottom debris on a screen of 0.701-mm. mesh (Tyler #24 screen[4]). Before sieving, we removed a subsample of sediment (about 300 cc.) from each bottom sample for analysis at the Sedimentological Laboratory, Florida State University. Their analyses included measurements of grain size, calcium carbonate, organic nitrogen, and organic carbon as well as statistical characteristics of mean grain size, sorting (as standard deviation), skewness, and kurtosis (Taylor and Saloman, 1969).

[4] References to trade names in this publication do not imply endorsement of commercial products.

DIVERSITY AND ABUNDANCE OF MOLLUSKS

We collected and identified 64 species of mollusks from bottom samples taken in Hillsborough Bay (Appendix). Of these species only 36 were represented by living individuals; furthermore, live mollusks were collected at only 26 of the 45 stations sampled. Samples at all stations where live mollusks were collected always included one or more of four species, i.e.: dwarf surf clam (*Mulinia lateralis*), paper mussel (*Amygdalum papyria*), common eastern nassa (*Nassarius vibex*), and stout tagelus (*Tagelus plebeius*). On an individual basis, *M. lateralis* was present in 65 percent of the station samples that contained live mollusks; the incidences of *A. papyria*, *N. vibex*, and *T. plebeius* were 58, 54, and 35 percent, respectively (table 1). The next most numerous mollusks were the crown conch (*Melongena corona*) and the lunar dove-shell (*Mitrella lunata*) which occurred at 6 of the 26 stations where live mollusks were found.

TABLE 1.—*Numbers of living mollusks by species and station collected from Hillsborough Bay, Fla., August and September 1963*

[Number of times a station sampled in parentheses]

Species	Station numbers																	
	7–1 (2)	7–2 (2)	7–3 (2)	8–1 (2)	8–2 (2)	8–3 (2)	8–4 (2)	8–5 (2)	8–6 (1)	8–7 (2)	8–8 (2)	8–9 (2)	8–10 (2)	9–1 (1)	9–2 (2)	9–3 (2)	9–4 (2)	9–5 (2)
Mulinia lateralis						1	2				4	2				800	1	
Amygdalum papyria												40				1		
Nassarius vibex	4															122	4	
Tagelus plebeius												7		1				
Melongena corona						1												
Mitrella lunata																1		
Tellina versicolor																		
Ensis minor																		
Mercenaria campechiensis																	1	
Macoma tenta																		
Crepidula plana																		
Bittium varium																		
Thracia sp.																1		
Modiolus americanus												5						
Anadara transversa																		
Crassostrea virginica																		
Retusa canaliculata																		
Polinices duplicatus																		
Odostomia acutidens																		
Mystella planulata												5				2		
Epitonium humphreysi																		
Corbula caribaea																		
Anachis obesa																		
Tagelus divisus																		
Urosalpinx tampaensis																		
Nucula proxima																		
Natica pusilla																		
Laevicarium mortoni																		
Haminoea succinea																		
Epitonium angulatum																		
Crepidula fornicata																		
Corbula barrattiana																		
Brachidontes exustus																		
Polymesoda caroliniana																		
Acteon punctostriatus																		
Ischnochiton papillosus						1					4							
Total number species	1	0	0	0	0	3	1	0	0	0	2	5	0	1	0	5	3	0
Total number individuals	4	0	0	0	0	3	2	0	0	0	8	59	0	1	0	925	6	0

TABLE 1.—*Numbers of living mollusks by species and station collected from Hillsborough Bay, Fla., August and September 1963*—Continued

[Number of times a station sampled in parentheses]

Species	Station numbers														
	9–6 (2)	9–7 (2)	9–8 (2)	9–9 (2)	9–10 (2)	10–14 (3)	10–15 (2)	10–16 (2)	10–17 (2)	10–18 (1)	10–19 (2)	10–20 (2)	10–21 (2)	10–22 (2)	10–23 (2)
Mulinia lateralis				4		21	63				10	1		35	
Amygdalum papyria						21	3				3	4		41	300
Nassarius vibex						9	10	3				1		4	5
Tagelus plebeius						12									
Melongena corona							1								
Mitrella lunata						203	359	1							30
Tellina versicolor							16	4			1			2	
Ensis minor						7								1	2
Mercenaria campechiensis								4			2			1	
Macoma tenta							7	4			2			1	
Crepidula plana						3		1							1
Bittium varium						10	1								10
Thracia sp.							2	1			1				
Modiolus americanus															
Anadara transversa							10				5				
Crassostrea virginica							3								
Retusa canaliculata							2								1
Polinices duplicatus														1	1
Odostomia acutidens							1								2
Mysella planulata															
Epitonium humphreysi							6							1	
Corbula caribaea								5			41				
Anachis obesa							22							1	
Tagelus divisus															
Urosalpinx tampaensis															
Nucula proxima															
Natica pusilla											1				
Laevicarium mortoni											2				
Haminoea succinea							3								
Epitonium angulatum															
Crepidula fornicata							3								
Corbula barratiana											1				
Brachidontes exustus											2				
Polymesoda caroliniana															1
Acteon punctostriatus															
Ischnochiton papillosus															
Total number species	0	0	0	1	0	8	17	8	0	0	12	3	0	10	10
Total number individuals	0	0	0	4	0	286	512	23	0	0	71	6	0	88	353

Species	Station numbers												Stations where collected	
	C (2)	C–1 (1)	C–2 (2)	C–3 (2)	C–4 (1)	C–5 (2)	C–6 (2)	C–7 (1)	C–8 (1)	C–8–1 (1)	C–8–2 (1)	C–9 (1)	Stations	Percentage of stations
													Number	*Percent*
Mulinia lateralis	129		268	99		8	150						17	65
Amygdalum papyria	26	1	16	80	2	3	22						15	58
Nassarius vibex		22	2	2		1	15						14	54
Tagelus plebeius	1		16	2					71	142	89		9	35
Melongena corona	10	1	4	5									6	23
Mitrella lunata			8										6	23
Tellina versicolor			8										5	19
Ensis minor				5		1							5	19
Mercenaria campechiensis													4	15
Macoma tenta													4	15
Crepidula plana	6												4	15
Bittium varium	17												4	15
Thracia sp.													4	15
Modiolus americanus	1			17			15						4	15
Anadara transversa			3										3	12
Crassostrea virginica			2	2									3	12
Retusa canaliculata													2	8
Polinices duplicatus													2	8
Odostomia acutidens													2	8
Mysella planulata	1												2	8
Epitonium humphreysi													2	8
Corbula caribaea													2	8
Anachis obesa				1									2	8
Tagelus divisus													1	4
Urosalpinx tampaensis			1										1	4
Nucula proxima													1	4
Natica pusilla													1	4
Laevicardium mortoni													1	4
Haminoea succinea	1												1	4
Epitonium angulatum													1	4
Crepidula fornicata													1	4
Corbula barratiana													1	4
Brachidontes exustus													1	4
Polymesoda caroliniana		1											1	4
Acteon punctostriatus													1	4
Ischnochiton papillosus													1	4
Total number species	9	4	10	9	1	4	4	0	1	1	1	0		
Total number individuals	192	25	328	159	2	13	202	0	71	142	89	0		

Live specimens of *M. lateralis*, *A. papyria*, *N. vibex*, and *T. plebeius* indicated bottom conditions by their presence or absence and by their abundance in relation to other live mollusks. On the basis of the occurrence and distribution of these four species, bottom environments were classified as healthy or marginal. Healthy stations were those where indicator species were less than 50 percent of all live mollusk species present; at marginal stations, the indicators represented 50 percent or more of all live species present. Unhealthy stations were those where no living mollusks were collected (fig. 1 and tables 2–4). The number of living mollusks was generally higher at healthy than at marginal stations except at marginal station 9–3 where *M. lateralis* and *N. vibex* were unusually abundant. Furthermore, on the basis of station classification the entire area of the bay was divisible into healthy, marginal, and unhealthy zones.

The four species selected as indicators for the bay, and perhaps the crown conch as well, may be useful for biological evaluation of the environment in estuarine water of the southeastern and Gulf States. Table 5 represents a summary of ecological literature and shows the extreme ranges of environmental conditions that these five mollusks can tolerate under natural conditions.

HEALTHY STATIONS

Eight stations, or about 18 percent of those having live mollusks, were classified as healthy. The average incidence of indicator species at these stations was 27 percent, and the average numbers per station were 11 species and 225 individuals (table 2).

TABLE 2.—*Biotic and physical characteristics of healthy benthic stations in Hillsborough Bay, Fla., August and September 1963*

Station	Species [1]	Individual [1]	Indicator species [1]	Depth	Mean sediment grain size	Sediment sorting	Sediment type	Bottom vegetation	Bottom salinity
	Number	*Number*	*Percent*	*M.*	*ø*	*ø*			*P.p.t.*
C	9	192	33	1.7	4.05	2.5	Coarse silt	*Gracilaria* sp	18.19
C-2	10	328	40	4.7	2.28	1.0	Fine sand	*Gracilaria* sp	18.56
C-3	9	213	44	2.0	2.78	1.6	Fine sand	*Gracilaria* sp	16.35
10-15	17	512	18	3.0	2.74	1.4	Fine sand	*Gracilaria* sp	21.82
10-16	8	23	13	6.0	3.15	1.5	Very fine sand	None	22.62
10-19	12	71	17	3.7	2.02	1.8	Fine sand	None	22.95
10-22	10	88	33	2.0	2.84	1.3	Fine sand	*Gracilaria* sp	22.43
10-23	10	353	20	1.0	2.59	.8	Fine sand	*Gracilaria* sp	21.26
Mean	11	225	27	3.0	2.80	1.5	Fine sand		20.52
Range			13–44	1.0–6.0	2.02–4.05	.8–2.5			18.19–22.95

[1] Collected alive.

TABLE 3.—*Biotic and physical characteristics of marginal benthic stations in Hillsborough Bay, Fla., August and September 1963*

Station	Species [1]	Individual [1]	Indicator species [1]	Depth	Mean sediment grain size	Sediment sorting	Sediment type	Bottom vegetation	Bottom salinity
	Number	*Number*	*Percent*	*M.*	*ø*	*ø*			*P.p.t.*
C-1	4	25	50	1.0	2.32	1.8	Fine sand	None	18.33
C-4	1	2	100	1.0	2.95	1.2	Fine sand	None	15.59
C-5	4	13	75	4.2	2.58	1.0	Fine sand	None	19.78
C-6	4	202	75	2.0	2.88	1.0	Fine sand	None	18.96
C-8	1	71	100	.7	2.51	1.1	Fine sand	None	.74
C-8-1	1	142	100	.7	2.95	1.6	Fine sand	None	1.15
C-8-2	1	89	100	.3	5.28	2.6	Medium silt	None	3.69
7-1	1	4	100	2.0	3.04	1.1	Very fine sand	None	17.79
8-3	3	13	50	3.6	4.09	2.2	Coarse silt	None	19.78
8-4	1	2	100	3.9	5.23	2.7	Medium silt	None	20.50
8-8	2	8	50	2.8	3.14	1.4	Very fine sand	None	16.56
8-9	5	57	60	1.0	2.51	.5	Fine sand	None	18.78
9-1	1	1	100	.3	2.53	.7	Fine sand	None	17.25
9-3	5	925	60	2.0	2.38	.8	Fine sand	None	18.37
9-4	3	6	67	2.4	2.25	.7	Fine sand	None	18.51
9-9	1	4	100	2.8	3.37	1.8	Very fine sand	None	17.70
10-14	8	267	50	1.0	2.68	.8	Fine sand	*Gracilaria* sp	20.61
10-20	3	6	100	3.9	2.88	1.6	Fine sand	None	22.92
Mean	3	102	80	1.9	3.09	1.4	Very fine sand		15.90
Range			50–100	.3–4.2	2.25–5.28	.5–2.7			.74–22.92

[1] Collected alive.

TABLE 4.—*Biotic and physical characteristics of unhealthy benthic stations in Hillsborough Bay, Fla., August and September 1963*

Station	Depth	Mean sediment grain size	Sediment sorting	Sediment type	Bottom vegetation	Bottom salinity
	M.	ø	ø			*P.p.t.*
C–7	0.7	−0.95	1.4	Very coarse sand	None	18.33
C–9	.7	−.77	2.1	Very coarse sand	None	16.22
7–2	4.2	5.76	2.3	Medium silt	*Gracilaria* sp.	17.79
7–3	2.7				None	17.61
8–1	3.9	5.65	2.5	Medium silt	None	18.78
8–2	3.3	2.93	1.3	Fine sand	None	19.04
8–5	10.3	7.40	2.0	Very fine silt	None	22.92
8–6	6.7	−1.90	2.0	Granule	None	18.60
8–7	3.3	4.77	2.8	Coarse silt	None	19.42
8–10	.7	3.31	1.4	Very fine sand	None	17.94
9–2	3.3	5.12	3.2	Medium silt	None	18.33
9–5	4.2	7.55	2.0	Very fine silt	None	19.74
9–6	12.1	6.91	2.2	Fine silt	None	22.38
9–7	3.6	7.84	1.8	Very fine silt	None	20.05
9–8	4.2	4.35	2.6	Coarse silt	None	19.42
9–10	1.0	2.88	1.2	Fine sand	None	18.75
10–17	10.9	4.46	2.3	Coarse silt	None	23.77
10–18	.7	−.96	2.7	Very coarse sand	None	22.11
10–21	3.6	3.62	1.5	Very fine sand	None	22.81
Mean	3.8	[1] 5.37	2.1	Medium silt		19.60
Range	.7–12.1	−1.90–7.84	1.2–3.2			16.22–23.77

[1] Negative grain sizes excluded.

TABLE 5.—*Range of tolerance in ecological factors and geographical distribution of the five most commonly collected mollusks in Hillsborough Bay, Fla., August and September 1963*

Species	Temperature	Salinity	pH	Turbidity	Depth	Current	Sediment type	Bottom type	Distribution
	°*C.*	*P.p.t.*			*M.*	*Cm./sec.*			
Mulinia lateralis	[1 2] 1–34	[3] 1.4–75	[2] 6.8–8.7	Tolerant [2 3]	[4 5] 1–4.7	[5] 9.4–90	Nonselective; fine sand and silt.[5 6 7 8]	Unvegetated [3]	Maine to Florida and Guf of Mexico.[9]
Amygdalum papyria	[1] 9–36	[10] 5–38	[2] 6.8–8.7	do [2 10]	[3 5] 1–4.7	[6] <90	Fine sand [5]	Unvegetated [5] Vegetated.	Maryland to Florida and Gulf of Mexico.[1 9]
Nassarius vibex	[1] 3–36	[1 11] 9–42	[2] 6.8–8.7	do [2 10]	[12] 1–15	[4 6] 8.6–90	Nonselective; sand and silt.[5 13]	Unvegetated [5 13] Vegetated.	Cape Cod to Florida and Gulf of Mexico.[9]
Tagelus plebeius	[1 2] 1–34	[1 7] 1–37	[2] 6.8–8.7	do [2]	[5 12] 1–4.7	[4 6] 30–90	Nonselective; sand and silt [5 14]	Unvegetated [5] Vegetated.	Cape Cod to Florida and Gulf of Mexico.[9]
Melongena corona	[2] 11–34	[15 16] 8–45	[2] 6.8–8.7	do [2 10]	[5 10] 1–4.7	[6] <90	Nonselective; shell, sand and silt [5 17]	Unvegetated [5 15 17]	Florida and Gulf of Mexico.[8 18]

[1] Parker, 1959.
[2] Saloman and Taylor, 1968.
[3] Breuer, 1962.
[4] Brett, 1963.
[5] This report.
[6] Taylor and Saloman, 1969.
[7] Hedgpeth, 1954.
[8] Marland, 1958.
[9] Abbott, 1954.
[10] Tabb, Dubrow, and Manning, 1962.
[11] Wells, 1961.
[12] Wass, 1965.
[13] Moore, Davies, Fraser, Gore, and Lopez, 1968.
[14] Allen, 1954.
[15] Tabb and Manning, 1961.
[16] Hathaway and Woodburn, 1961.
[17] Menzel, 1956.
[18] Hedgpeth, 1953.

Most of the healthy stations (60 percent) were at the mouth of Hillsborough Bay along transect 10. The most numerous and diverse mollusk assemblage was at station 10–15, where we collected 512 individuals and 17 species. At the upper end of the bay, conditions were healthy at stations C, C–2, and C–3 where more than average current (C–2 and C–3) and benthic algae (C, C–2, and C–3) maintain a favorable environment for many mollusks despite the proximity of effluent discharged from the Tampa Sewage Treatment plant at Hooker Point. Throughout the rest of the bay, all stations were either marginal or unhealthy (fig. 1).

The predominant sediment type at healthy stations was fine sand (2.80 ø). Sediment sorting was poor (1.5 ø), according to the classification of Folk (1964), and is a reflection of the weak current system in the bay (Taylor and Saloman, 1969). A number of authors have noted that fine sand is well suited for colonization by a variety of

mollusks (Jones, 1950; Pratt, 1953; Thorson, 1956; Sanders, 1958; McNulty, 1961; Brett, 1963). Another feature of most healthy stations was the occurrence of a red alga, *Gracilaria* sp., which is a source of organic detritus and provides a base for attachment of epiphytic mollusks.

Salinity at healthy stations was between 18 p.p.t. (upper bay stations C, C–2, and C–3) and 23 p.p.t. (transect 10). The combination of relatively high mollusk diversity and reduced salinity at the upper bay stations indicated that a factor other than salinity prevented the establishment of an equivalent variety of mollusks at most marginal and unhealthy stations.

MARGINAL STATIONS

At the 18 stations classified as marginal at least 50 percent of the live mollusks were indicator species, and the average incidence of indicators at these stations was 80 percent. The average number of species per station represented by live animals was only 3; the mean number of individuals was 102 (table 3). In comparison with the healthy stations, marginal stations had about one-fourth as many species of mollusks and about one-half as many individuals.

Sediments at marginal stations ranged from fine sand to medium silt. The average sediment type was very fine sand (3.09ϕ)—a somewhat finer particle size than the average size at healthy stations. Sediment sorting was poor (1.4ϕ) and very close to the figure for healthy stations.

Bottom vegetation (*Gracilaria* sp.) was found at only one marginal station. That station had a substrate of fine sand and more species of mollusks than any other station.

Low salinity (less than 4 p.p.t.) near the mouth of the Alafia River was probably responsible for fewer species of mollusks at stations C–8, C–8–1, and C–8–2. The only species present in this area was *Tagelus plebeius*.

Data for DO (dissolved oxygen) indicated that from June through August bottom water in the bay between transect 10 and McKay Bay becomes anaerobic (FWPCA, personal communication; see footnote 3). At other times, however, DO values are generally above 3 ml./liter and would not prove limiting. Changes in the DO at stations regarded as marginal may create a more favorable environment for mollusks during other seasons.

UNHEALTHY STATIONS

No live mollusks were collected at 19 stations classified as unhealthy (fig. 1). Two of these stations were on the eastern shore of the bay (8–10 and 9–10) and adjacent to an extensive area of gypsum spoil—a byproduct of the phosphate industry. The gypsum forms a crust on the bottom that virtually eliminates macrobenthic organisms.

Sediments at other unhealthy stations had a mean grain size that varied from −1.90 ϕ (granule) to 7.84 ϕ (very fine silt)—see table 4. Sediments were coarse at stations near spoil islands left from channel construction and on a natural, shelly shoal (C–7). Absence of mollusks in coarse sediments probably resulted from the grinding action of large particles powered by wave action. Stations with fine sediments were in comparatively deep water. There the sediments had a high concentration of the toxic compound, hydrogen sulfide, and are probably anaerobic, or nearly so, at all times (Florida State Board of Health, 1965).

ECOLOGICAL ZONES

Isopleths were drawn between similar stations to represent approximate boundaries of healthy, marginal, and unhealthy zones in Hillsborough Bay (fig. 2). Calculation of the area within each zone showed that only 22 percent of the bay falls in the healthy category, 36 percent is marginal, and 42 percent is unhealthy. Most healthy zones were near the mouth of the bay where the solid and soluble products of pollution were least concentrated. Marginal zones were on the bottom slopes between the three unhealthy zones that were along the eastern and western shores and in midbay ship channels. Observations in Raritan Bay (Dean and Haskin, 1964) and Biscayne Bay (McNulty, 1966) suggest that pollution abatement in Hillsborough Bay would favor progressive repopulation of marginal zones by a more normal assemblage of benthic plants and animals. In heavily silted areas of the unhealthy zones, however, biological restoration would probably require a long period of time.

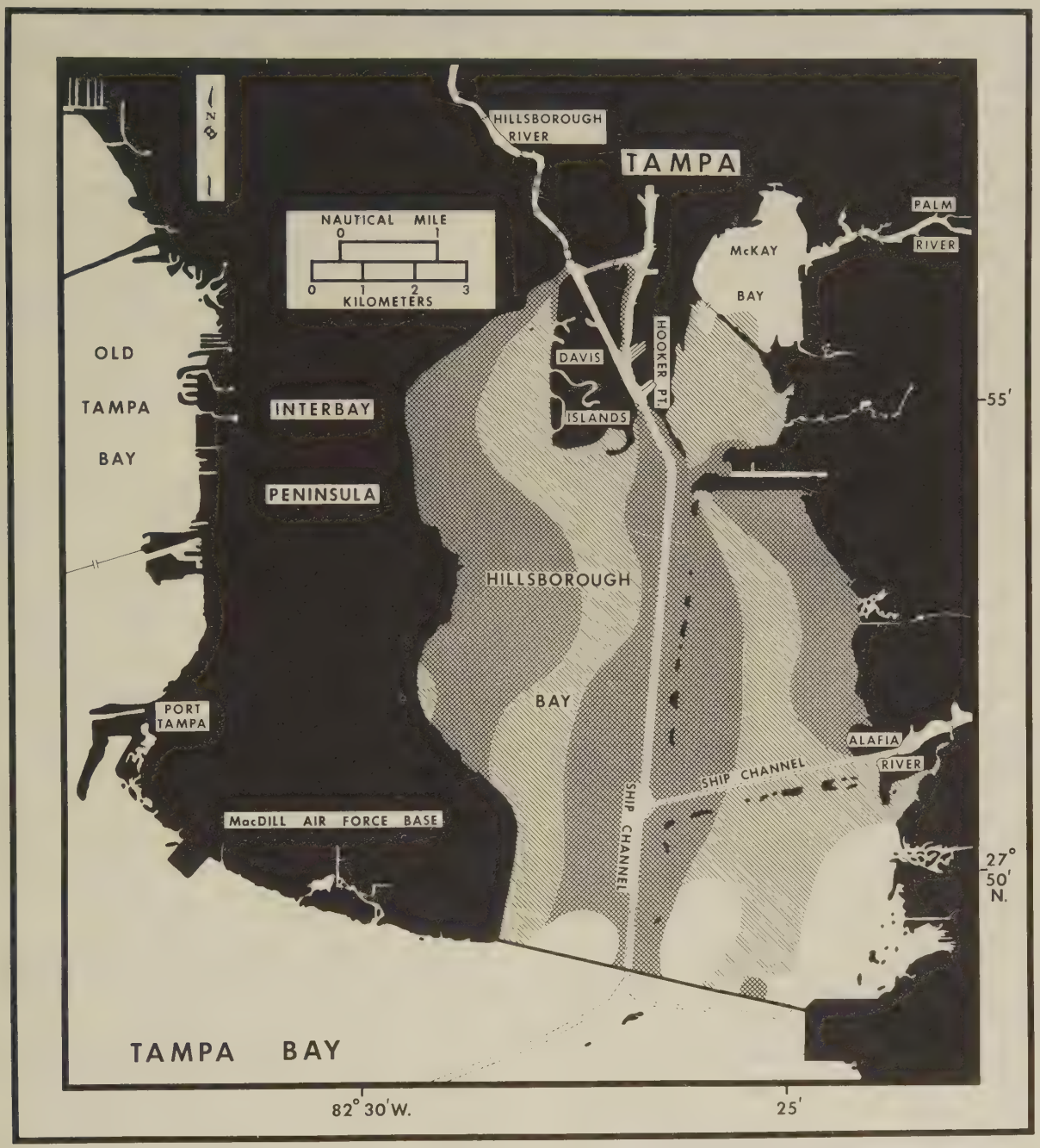

FIGURE 2.—Ecological zones in Hillsborough Bay, Fla., based on the comparative diversity of mollusks—healthy zone (unshaded); marginal zone (hatching); unhealthy zone (cross hatching)—August and September 1963.

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APPENDIX

A CHECKLIST OF MOLLUSKS FOUND IN HILLSBOROUGH BAY, FLORIDA, AUGUST AND SEPTEMBER 1963

We collected and identified 64 species of mollusks representing 43 families. Determinations were based on standard taxonomic works (Abbott, 1954; Perry and Schwengel, 1955; Warmke and Abbott, 1962; Keen, 1963; Abbott, 1968) and by comparison with specimens in the U.S. National Museum (+). An asterisk (*) indicates that the species was collected alive.

Class Gastropoda

Family Neritidae
Neritina reclivata (Say)
Family Rissoidae
Rissoina chesneli Michaud
Family Vitrinellidae
Cyclostremiscus sp.
Family Cerithiidae
**Bittium varium* (Pfeiffer)
Seila adamsi (H. C. Lea)
Family Triphoridae
Triphora nigrocincta (C. B. Adams)

Family Epitoniidae
**Epitonium angulatum* (Say)
**Epitonium humphreysi* (Kiener)
Epitonium rupicola (Kurtz)
Family Calyptraeidae
**Crepidula fornicata* (Linné)
**Crepidula plana* Say
Family Naticidae
**Natica pusilla* Say
**Polinices duplicatus* (Say)
Family Muricidae
**Urosalpinx tampaensis* (Conrad)
Family Columbellidae
**Anachis obesa* (C. B. Adams)
+Anachis semiplicata (Stearns)
**Mitrella lunata* (Say)
Family Melongenidae
**Melongena corona* (Gmelin)
Family Nassariidae
**Nassarius vibex* (Say)
Family Olividae
Olivella perplexa Olsson
Family Marginellidae
Prunum apicinum (Menke)
Family Atyidae
**Haminoea succinea* (Conrad)
Family Retusidae
**Retusa canaliculata* (Say)
Family Pyramidellidae
*+*Odostomia acutidens* Dall
Odostomia impressa (Say)
+Odostomia producta (Dall)
+Turbonilla conradi Bush.
Family Acteocinidae
Cylichna bidentata (Orbigny)
Family Acteonidae
**Acteon punctostriatus* (C. B. Adams)
Family Ellobiidae
Melampus coffeus (Linné)

Class Amphineura

Family Ischnochitoniidae
**Ischnochiton papillosus* (C. B. Adams)

Class Pelecypoda

Family Nuculidae
**Nucula proxima* Say
Family Nuculanidae
Nuculana acuta Conrad
Family Arcidae
**Anadara transversa* (Say)
Family Mytilidae
**Amygdalum papyria* (Conrad)
**Brachidontes exustus* (Linné)
**Modiolus americanus* (Leach)
Modiolus demissus granosissima (Sowerby)
Family Pinnidae
Atrina rigida (Lightfoot)
Family Ostreidae
**Crassostrea virginica* (Gmelin)
Family Carditidae
Cardita floridana Conrad
Family Corbiculiidae
**Polymesoda caroliniana* (Bosc)
Family Leptonidae
**Mysella planulata* (Stimpson)
Family Cardiidae
**Laevicardium mortoni* (Conrad)
Family Veneridae
Chione cancellata (Linné)
**Mercenaria campechiensis* (Gmelin)
Parastarte triquetra (Conrad)
Family Petricolidae
Petricola pholadiformis Lamarck
Family Tellinidae
Macoma constricta (Bruguière)
**Macoma tenta* Say
Tellina alternata Say
Tellina lineata Turton
**Tellina versicolor* DeKay
Family Semelidae
Semele bellastriata (Conrad)
Semele proficua (Pulteney)
Family Donacidae
Donax variabilis Say
Family Sanguinolariidae
**Tagelus divisus* Spengler
**Tagelus plebeius* (Lightfoot)
Family Solenidae
**Ensis minor* Dall
Family Mactridae
Mactra fragilis Gmelin
**Mulinia lateralis* (Say)
Family Corbulidae
**Corbula barratiana* C. B. Adams
**Corbula caribaea* Orbigny
Family Pholadidae
Cyrtopleura costata (Linné)
Family Lyonsiidae
Lyonsia hyalina floridana Conrad
Family Thraciidae
**Thracia* sp.

MIGRATION OF JUVENILE SALMON AND TROUT INTO BROWNLEE RESERVOIR, 1962–65

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ABSTRACT

Migrations of juvenile chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), sockeye and kokanee salmon (*O. nerka*), and rainbow trout (*Salmo gairdneri*) from the Snake and Weiser Rivers and from Eagle Creek were studied. Populations of fish were sampled with floating traps above the reservoir and a fixed louver trap in Eagle Creek near the lower end of Brownlee Reservoir. Age and length of fish, timing of migration, and numbers of fish of native or hatchery origin were determined. This information was needed to evaluate the effect of Brownlee Reservoir on migrations of anadromous fish.

Brownlee Reservoir was created when a high-head hydroelectric dam was built in 1958 at the upstream end of Hells Canyon on the Snake River. The 92-km. long reservoir forms part of the boundary between Idaho and Oregon. At full pool, it is 92 m. deep and less than 1 km. wide; the upper end (22 km.) is relatively shallow and essentially riverine.

BCF (Bureau of Commercial Fisheries) chose Brownlee Reservoir for an extensive research program to determine how a large impoundment affects the passage of salmon and trout. The research, begun in the spring of 1962, comprised five studies: (1) limnology of the reservoir system (Ebel and Koski, 1968), (2) upstream migration of adult chinook salmon (*Oncorhynchus tshawytscha*) through the reservoir (Trefethen and Sutherland, 1968), (3) migration of juvenile salmon and trout into the reservoir (this report), (4) distribution and movement of juvenile salmon in the reservoir (Durkin, Park, and Raleigh, 1970), and (5) migration of juvenile salmon and trout from the reservoir (Sims, 1970).

Three major streams—the Snake, Burnt, and Powder Rivers—and more than a dozen minor streams, most of which have intermittent flows, are tributaries to Brownlee Reservoir. Previous investigations had shown that most of the streams supported local populations of rainbow trout (*Salmo gairdneri*), but chinook salmon and steelhead trout (the anadromous form of rainbow trout) spawned in only three of the streams. Spring- and fall-migrating steelhead trout and spring-migrating chinook salmon spawned in Eagle Creek, a tributary of the Powder River, and in the Weiser River, a tributary of the Snake River (fig. 1). Fall-migrating chinook salmon spawned in the Snake River about 257 km. above the dam.

Wild (native) salmon and trout fingerlings entered the reservoir during each year of study (1962–65). From 1963 on, most of the chinook salmon spawners were diverted to a hatchery. In 1964 and 1965, therefore, hatchery-reared progeny of fall chinook salmon from the lower Columbia River were released in the Snake River spawning area above the reservoir. We wished to study the effect of a large impoundment on other species of salmon, so yearling coho (*O. kisutch*) from the lower Columbia River and sockeye salmon (*O. nerka*) from the Skeena River were included in the hatchery releases in 1964 and 1965, respectively. In 1963, 1964, and 1965, migrations of wild kokanee (*O. nerka*) entered the reservoir from the Payette River system.

This report provides estimates of age and length of fish from each population at the time of entry into the reservoir, time and duration of downstream migrations, and numbers of fish of native and hatchery origin for 1962 through 1965.

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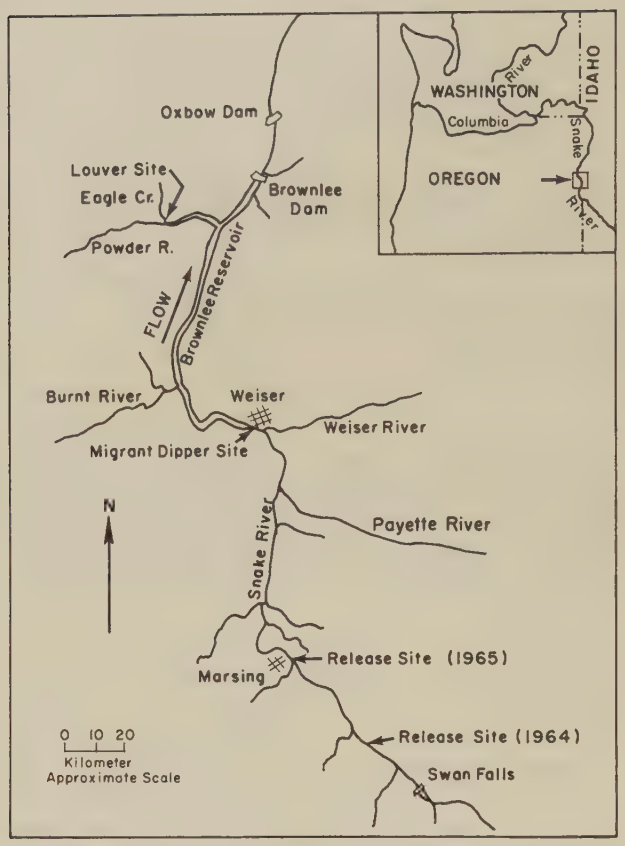

FIGURE 1.—Study area showing locations of sampling equipment used to assess migrations of juvenile salmon and rainbow trout to Brownlee Reservoir.

SAMPLING SITES, EQUIPMENT, AND PROCEDURES

The plan of study was to sample populations of migrating fish before they entered the reservoir, to determine their characteristics, and to estimate their abundance. This plan required the installation of floating fingerling traps in the Snake River above the reservoir and a fixed louver in Eagle Creek, a tributary of the Powder River near the lower end of Brownlee Reservoir (fig. 1).

Sample catches from the populations of juvenile chinook salmon in the Snake and Weiser Rivers early in the study established that juvenile fall chinook salmon migrated from the Snake River at age 0, whereas juvenile spring chinook salmon migrated from the Weiser River at age 1. Thus, it was possible to separate these two populations on the basis of age or size and to sample them from a single location below the confluence of the two rivers.

SNAKE RIVER

The sampling site for the Snake and Weiser Rivers was about 8 km. below their confluence and about 4 km. above the reservoir. Flows during the spring were 383 to 1,372 c.m.s. (cubic meters per second) and averaged 744 c.m.s. At average flow, the Snake River channel at this location was about 152 m. wide and had a maximum depth of 7.6 m.

The sampling device in the Snake River was a modified "migrant dipper" (Mason, 1966)—a self-cleaning, floating fingerling trap with louvered leads (fig. 2). The basic unit consisted of a trap section, 12.2 m. long by 7.6 m. wide by 1.8 m. deep, with fixed louver leads that extended 9.8 m. upstream at a 10° angle to the flow. A self-cleaning traveling screen formed the rear of the trap, and a metal screen floor extended upstream to the two fixed louver sections. The louvers guided the fish into the trap area where a continuously rotating scoop dipped the fish and deposited them into a trough. The fish were then flushed into a holding pen at the side of the trap.

Fish were captured in traps from 1962 through 1965. We carried out feasibility tests with one trap in 1962 and examined the horizontal distribution of downstream migrants at the same time. In the spring of 1963, two migrant dipper traps were attached to an overhead cable and positioned in the main current. Floating louver extensions were added to the fixed louver sections to increase the sampling capability. In attempts to increase the catch, the louver angle and lengths were altered each year (table 1). In 1962, the traps were operated continuously from mid-April until early July and then intermittently until December. On the basis of these early experiments, the operations in 1963–65 began in mid-March and ended in July.

TABLE 1.—*Traps used in the Snake River and configuration of attached louver arrays*

Year	Traps	Details of louver leads		
		Angle	Length	Width at mouth
	Number	*Degrees*	*M.*	*M.*
1962	1	10	9.7	13.7
1963	2	30	22.0	30.5
1964	2	15	22.0	21.4
1965	1	15	47.6	30.5

Fish captured in the traps and subsequent estimates of the magnitude of migration were classi-

FIGURE 2.—Floating traps (migrant dippers) used to sample migrations of juvenile salmon and rainbow trout in the Snake River above Brownlee Reservoir.

fied by age group on the basis of lengths determined by daily sampling. The length-age relation was established by scale analysis. Fingerlings in their first year of life are termed age-group 0; these fish become age-group I on January 1 of the succeeding year.

Marked fish were used to estimate the proportion of the migration captured by the traps. The proportion varied with trap design and position, size and species of migrants, and flow and turbidity of the river. A portion of the daily catch of fish was marked, transported 3.2 km. upstream, and released for recapture. They were marked by age group and released at scheduled intervals during the day and night.

Fish marked to assess the migration from the Snake River were tattooed (Volz and Wheeler, 1966). This method provided many combinations of marks that were durable and could be easily detected. Juvenile salmon from each population were fin-clipped or jaw-tagged each year for subsequent identification as they moved through the reservoir.

EAGLE CREEK

The sampling site at Eagle Creek was 183 m. upstream from its confluence with the Powder River and about 460 m. from the reservoir (fig. 1). The stream at this point was 15 m. wide at normal flows. Except during maximum runoff in the spring, flows seldom exceeded 57 c.m.s.

Samples of downstream migrants were obtained with a stationary louver device (Bates and Vinsonhaler, 1957)—see figure 3. In 1962, the louver (18.3 m. long and 0.9 m. high) was positioned at a 30° angle to the stream bank. In 1963, to increase the catch and eliminate selectivity for larger fish, the angle was decreased to 15° and the length extended to 36.6 m. In 1964, the channel was altered above the louver to straighten the approach flow.

Fish from Eagle Creek were collected from three sources and marked in a variety of ways. Most fish were stained with Bismark Brown Y dye[1] (Deacon, 1961) and released above the sam-

[1] Trade names referred to in this publication do not imply endorsement of commercial products by the Bureau of Commercial Fisheries.

FIGURE 3.—Stationary louver used to estimate the number of juvenile salmon and rainbow trout migrating into Brownlee Reservoir from Eagle Creek.

pling site to determine trapping efficiencies of the louver. Fish to be stained could be held in the cooler waters of Eagle Creek with little difficulty, whereas they could not be kept alive for sufficient time to stain them in the warmer waters of the Snake River. We obtained test fish mainly from irrigation bypass traps and fyke nets located several kilometers upstream. When sufficient numbers of migrating fish were not available from these sources, we used fingerlings captured at the louver. Periodically, groups of migrants from Eagle Creek were marked by fin-clipping, jaw tags, or plastic thread tags [2] for identification in the reservoir.

DOWNSTREAM MOVEMENT, AGE, LENGTH, AND TIME OF ENTRY INTO THE RESERVOIR OF JUVENILE SALMON AND TROUT

The characteristics of the migrations into Brownlee Reservoir were determined from catches at the sampling sites. Timing and peaks of runs are expressed as weekly percentages of the estimated numbers of fish in the migrations. About 10 percent of each daily catch was examined for data on length and age.

MIGRATIONS OF WILD SALMON AND TROUT

Migrations of wild chinook salmon and steelhead trout juveniles entered the reservoir from three tributaries. Fall chinook entered from the Snake River, whereas spring chinook and steelhead entered from Eagle Creek and Weiser River.

Fall Chinook Salmon

The movement of juvenile fall chinook salmon from the Snake River to Brownlee Reservoir began about mid-April and peaked in mid-May in 1962 and 1963 (fig. 4). About 75 percent of the migration took place during a 2-week period, and nearly all of the fish had migrated by mid-June. Principal movement was between sunrise and 10 a.m. and from 3 to 7 p.m.

[2] Developed by the Fish Commission of Oregon.

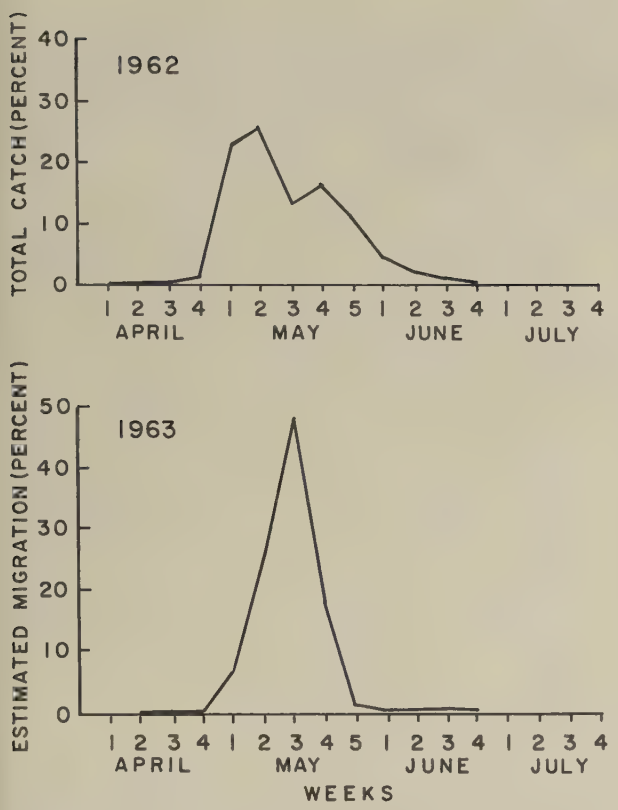

FIGURE 4.—Timing of migration of native juvenile fall chinook salmon (age-group 0) from the Snake River to Brownlee Reservoir by weekly periods, 1962–63.

The size of native juvenile fall chinook salmon increased throughout the migration period (table 2). Early migrants in 1962 averaged 52 mm.; by the final week, average length had increased to 71 mm. The migrants averaged larger in 1963—73 mm. at the start and 81 mm. at the end of the migration period.

Spring Chinook Salmon

Spring chinook salmon enter Brownlee Reservoir from Weiser River and Eagle Creek; their season of spawning is similar, but the sizes and seasons of migration of the juveniles into the reservoir are substantially different.

Weiser River population.—Juvenile spring chinook salmon from the Weiser River first appeared at the Snake River trap in early April and peaked in late April or early May (fig. 5). The migration was nearly complete by late May in all years. Daily catches of spring chinook salmon were greatest between 7 and 11 a.m. and 3 and 7 p.m. except during the peak when diurnal highs were not

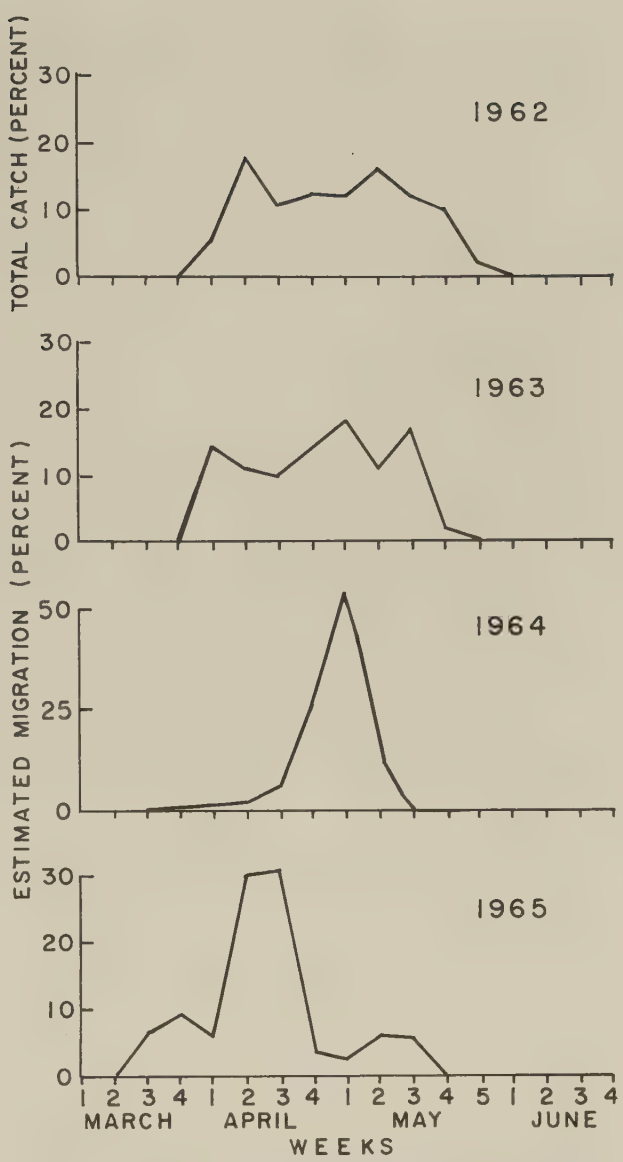

FIGURE 5.—Timing of migration of juvenile spring chinook salmon from the Weiser River to Brownlee Reservoir by weekly periods, 1962–65.

clearly defined. Daily catches were lowest between 10 p.m. and 4 a.m.

The size of spring chinook salmon from the Weiser River differed from that of wild fall chinook salmon from the Snake River in 1962–63; spring fish were age-group I and distinctly larger than fall fish, which were age-group O. In 1964 and 1965, however, the difference between these wild spring chinook salmon and the hatchery-reared fall chinook salmon was less apparent by late April when the length ranges merged. In

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TABLE 2.—*Lengths of wild juvenile fall chinook salmon from the Snake River during migration past sampling site, 1962–64*

Year	Length of fish at stage of migration					
	Early [1]			Late [2]		
	Fish	Mean	Range	Fish	Mean	Range
	Number	*Mm.*	*Mm.*	*Number*	*Mm.*	*Mm.*
1962	76	52	33–80	434	71	47–103
1963	97	73	48–99	133	81	67–98
1964	[3]			146	79	61–90

[1] Mid-April to mid-May.
[2] Mid-May to mid-June.
[3] No discernible fish of this group in sample.

1964 and 1965, the two populations were separated by the percentage of each age group in the daily sample as estimated from scale analysis.

The average length of spring chinook salmon varied from 106 mm. in 1962 to 149 mm. in 1964 (table 3). Each year the average size increased from the beginning to the end of the migration.

A few large individuals (215–260 mm.) were captured in 1963 and 1964, but the total constituted less than 1 percent of the catch. These fish (age-group III) appeared at the trap early in the season during extremely high flows from the Weiser River.

TABLE 3.—*Lengths of juvenile spring chinook salmon from the Weiser River during migration past sampling site in the Snake River, 1962–65*

Year	Length of fish at stage of migration					
	Early [1]			Late [2]		
	Fish	Mean	Range	Fish	Mean	Range
	Number	*Mm.*	*Mm.*	*Number*	*Mm.*	*Mm.*
1962	8	106	95–117	104	134	125–151
1963	438	108	94–140	52	142	116–155
1964	249	112	100–145	81	149	126–165
1965	19	119	101–130	22	140	120–155

[1] April to peak of migration (late April or early May).
[2] From peak of migration through May.

Eagle Creek population.—Juvenile spring chinook salmon from Eagle Creek migrated downstream most of the year except during the summer when flows averaged less than 1 c.m.s. (fig. 6). The principal migration was in the fall when flows at the trapping site exceeded 1.5 c.m.s. As irrigation was reduced at this time, most of the flow remained in the stream channel, and water temperatures ranged from 0° to 13° C. Winter migrations were small and occurred only during short-term increases in water temperature and flow. A secondary migration took place in the spring as water temperature and flows again increased. The migration declined just before high flows from spring rain and melting snow (fig. 6). Periodic sampling during the high flows suggested that few chinook salmon were migrating. As water levels receded, however, fish were taken in limited numbers until the upstream diversion of water for irrigation greatly reduced the flows at the louver. Water temperatures increased in the spring from near freezing to about 8° C.

Chinook salmon of age-group O dominated the migration in the fall. These fish emerged from the gravel in the spring and were the offspring of adults that had spawned in late summer and early fall of the previous year. The size of the O-group fish varied slightly from year to year and throughout the migration period (table 4).

Juvenile chinook salmon that moved downstream from January into late spring were primarily age-group I fish. A small number of age-group 0 (average, 60 mm.; range, 41–80 mm.) was sampled from April through June 1963. Some age-group II fish—less than 3 percent of the total

TABLE 4.—*Lengths of juvenile spring chinook salmon at beginning and end of spring and fall migrations at Eagle Creek, 1962–65*

Year	Spring migration								Fall migration							
	Age-group 0				Age-group I				Age-group 0				Age-group I			
	Beginning		End		Beginning		End		Beginning		End		Beginning		End	
	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
	Mm.	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
1962	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	78	53–109	84	60–111	119	112–120	132	[2] 115–168
1963	[3]	[3]	61	45–80	86	65–105	93	71–98	87	64–118	89	60–116	144	130–152	[3]	[3]
1964	[3]	[3]	66	58–78	90	72–108	94	72–130	102	76–121	103	78–125	158	—158	[3]	[3]
1965	[3]	[3]	[2]	[2]	100	86–118	111	83–119	108	83–119	[1]	[1]	[1]	[1]	[1]	[1]

[1] Not in operation.
[2] Few fish sampled.
[3] Not in catches.

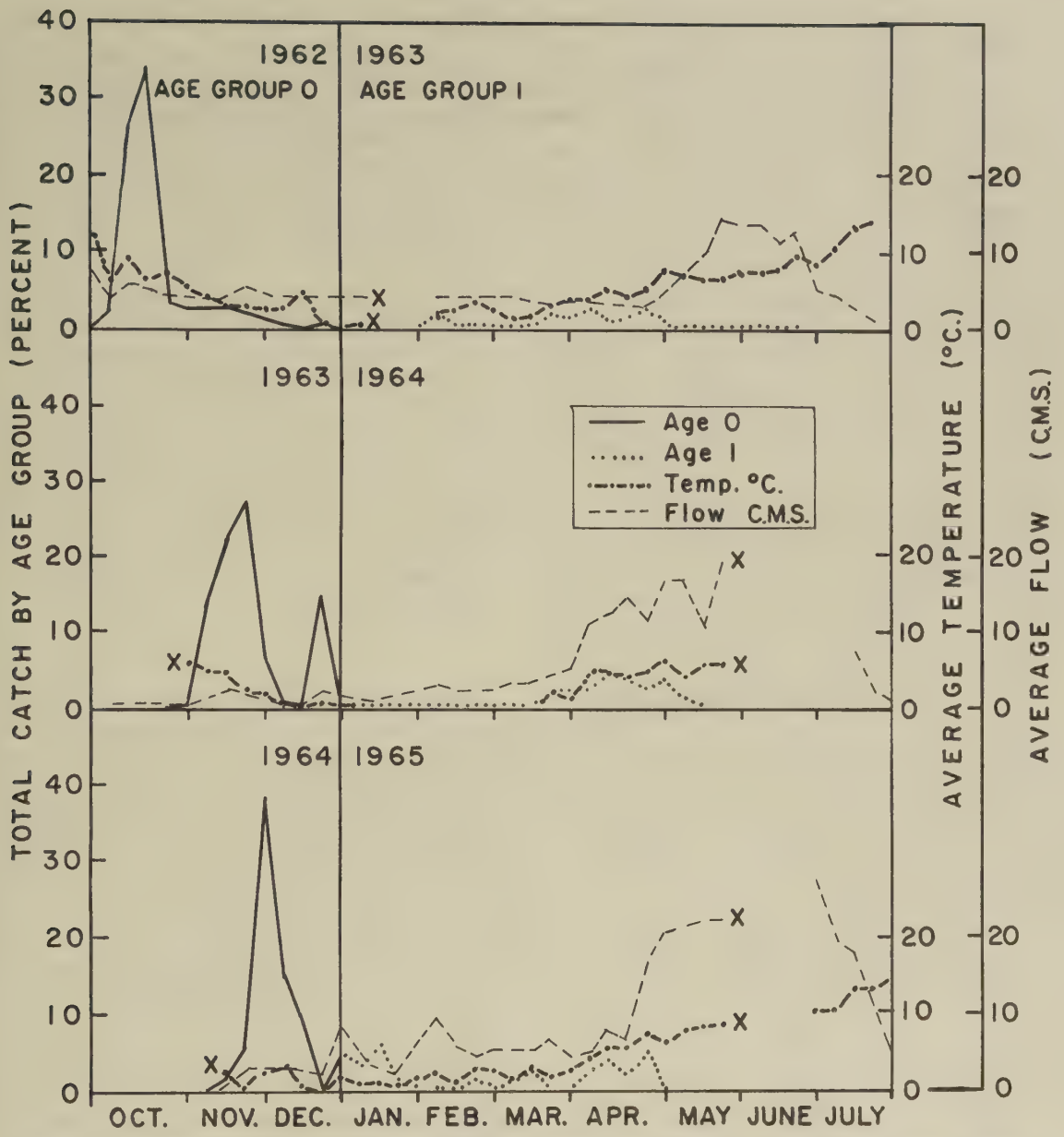

FIGURE 6.—Timing of migration of spring chinook salmon (age-groups O and I) from Eagle Creek to Brownlee Reservoir in relation to water temperature and flow, 1962–65 (x indicates periods of no data).

catch—were taken each spring. These fish averaged 140 mm. (126–180 mm.) and were scattered throughout the migration.

Most fish moved downstream past the louver at night—between 6 and 12 p.m. Few fish were caught through the rest of the 24-hour period except during high flows and turbid water; at these times fish moved downstream throughout the day and night.

Kokanee

Kokanee salmon from the Payette River system appeared at the Snake River sampling site in mid-June in 1963–65. The migration was evident for 3 or 4 weeks, but most of the fish moved downstream during a 1-week period (fig. 7). Kokanee averaged 118 to 120 mm. long through the 1964 migration and 93 to 108 mm. through the 1965 season (table 5).

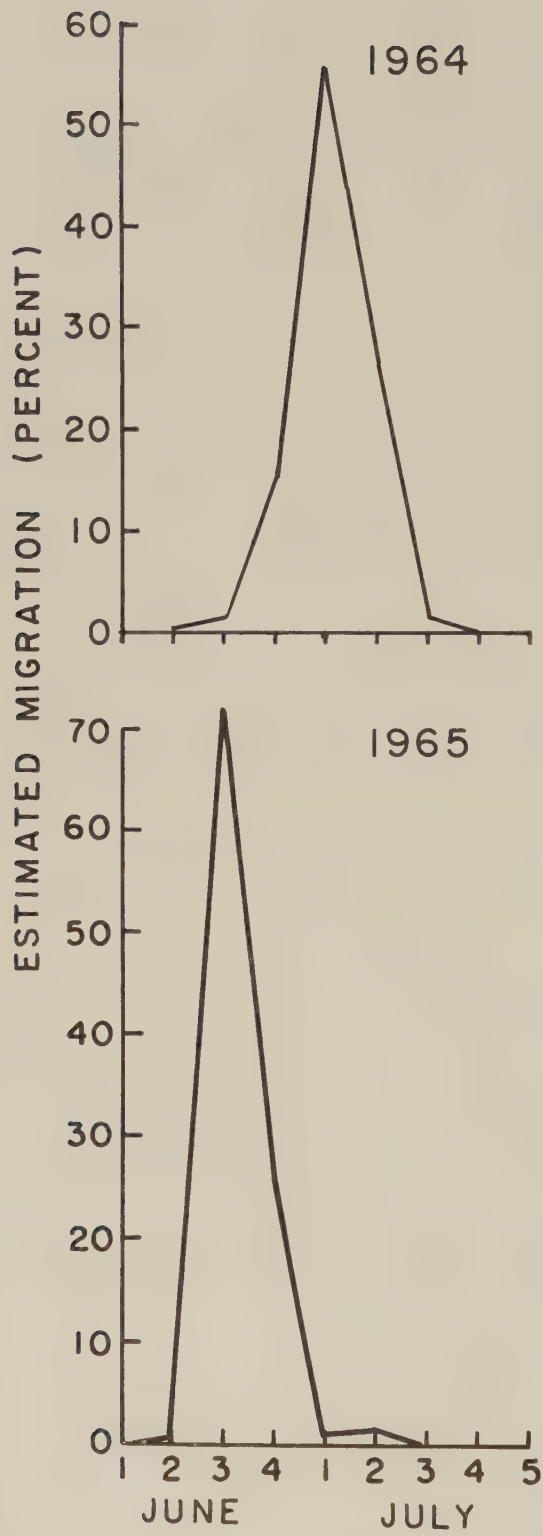

FIGURE 7.—Timing of migration of kokanee salmon from the Snake River to Brownlee Reservoir, 1964–65.

Rainbow Trout

Anadromous rainbow trout spawned in the same tributaries as spring chinook salmon. Offspring of the anadromous form could not be separated from resident native and planted rainbow trout that complete their life cycle in fresh water. Studies on the entry of trout into the reservoir included young from all three groups.

TABLE 5.—*Lengths of juvenile kokanee salmon during migration past sampling site in Snake River, 1963–65*

Year	Length of fish at stage of migration					
	Early [1]			Late [2]		
	Fish	Mean	Range	Fish	Mean	Range
	Number	*Mm.*	*Mm.*	*Number*	*Mm.*	*Mm.*
1963	7	[3]	100–110	3	[3]	128–142
1964	279	118	88–140	107	120	104–146
1965	166	93	80–110	151	108	70–155

[1] First week.
[2] Last week.
[3] Insufficient sample.

Trout migrated from the Snake River in the spring (fig. 8) at the same time as the chinook salmon populations. Time of peak migration varied but was in late April or May 1962–65. Age groups were from O to IV, but most were age-group I and II. Size overlap was considerable among age-groups I and II. Table 6 shows the age groups and length-frequency ranges for 1963.

The movement of rainbow trout from Eagle Creek (fig. 9) also took place primarily in the spring; about 75 percent of the fish migrated in late spring, at a time of high flows. A smaller run peaked in the fall. Fish of age-groups I and II dominated the run in the spring. Age-groups O and I were dominant in the fall; however, all age-groups O through IV were represented. Table 7 shows the size ranges.

MIGRATIONS OF HATCHERY-REARED SALMON

Most of the chinook salmon spawners were diverted to hatcheries from 1963 through 1965. In 1964 and 1965, hatchery-reared fingerling salmon were released at the Snake River spawning area, 88 to 120 km. above the reservoir. Chinook salmon fingerlings from fall migrating adults were released in 1964 and 1965. Coho salmon fingerlings were released in 1964 and sockeye salmon fingerlings in 1965.

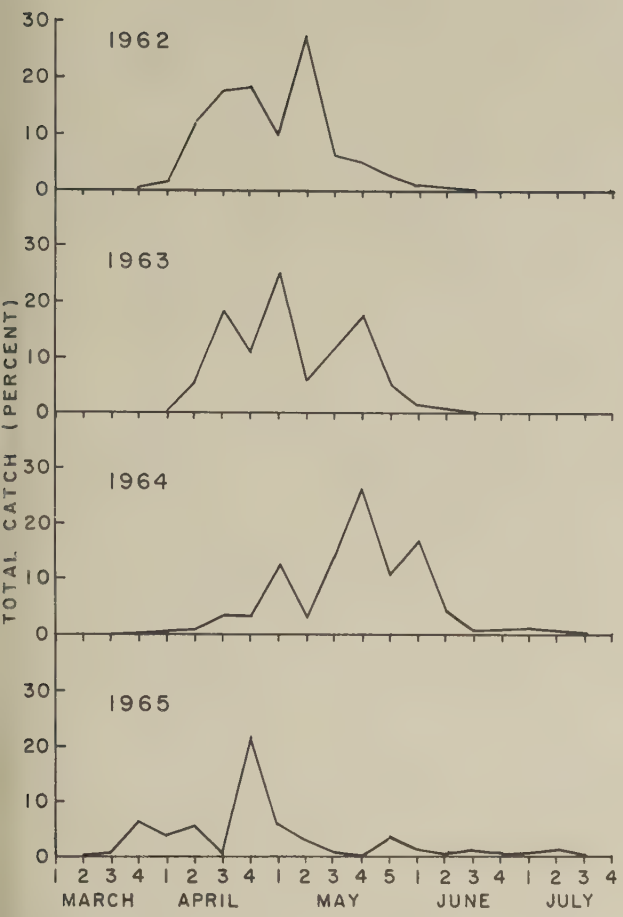

FIGURE 8.—Timing of migration of juvenile rainbow trout to Brownlee Reservoir from the Snake River, 1962–65.

TABLE 6.—*Age groups and lengths of juvenile rainbow trout captured in the migrant dipper traps in the Snake River above Brownlee Reservoir in 1963*

Age group	Fish	Mean length	Range
	Number	*Mm.*	*Mm.*
0	2	(1)	95–100
I	502	177.1	125–210
II	276	239.8	190–285
III	34	294.1	275–340
IV	1	(1)	382

[1] Insufficient sample.

TABLE 7.—*Age groups and lengths of juvenile rainbow trout from Eagle Creek during migration past sampling site in fall 1962*

Age group	Fish	Mean length	Range
	Number	*Mm.*	*Mm.*
0	119	78.0	52–109
I	228	141.7	90–183
II	16	200.0	180–265
III	3	(1)	225–270
IV	1	(1)	285

[1] Insufficient sample.

Fall Chinook Salmon

Hatchery-reared juveniles of fall chinook salmon were released in the Snake River above the reservoir in 1964 and 1965 to supplement the dwindling smolt migrations of wild fall chinook salmon. About 250,000 fall chinook salmon were released 120 km. above the reservoir from March 30 to April 3, 1964, when water temperatures averaged 9.5° C. In 1965, 592,000 juvenile fish were released 88 km. upstream from the reservoir from March 15 to 25, when the water temperature averaged 9.8° C. A tank truck transported the fish from hatcheries on the lower Columbia River. The fish were released during daylight.

The migrations of hatchery chinook salmon overlapped with migrations of wild spring chinook (age-group I) from the Weiser River. In 1964, juvenile chinook salmon from hatchery releases were recovered at the Snake River sampling site within 3 days after the first release. Downstream migration continued until late June, but catches were highest in mid-May (fig. 10). The migration in 1965 was longer and the peak less well defined.

The lengths of hatchery-reared chinook salmon increased as the season progressed and by late April were the same size as those of the age-group I wild chinook salmon from Weiser River. The hatchery fish captured at the migrant dipper in 1964 averaged 74 mm. (56–100 mm.) early in the season and 112 mm. (91–135 mm.) near the end of the migration (table 8). In 1965, the hatchery fish averaged 69 mm. (46–90 mm.) at the start of migration and 112 mm. (96–125 mm.) at the end.

TABLE 8.—*Lengths of hatchery-reared juvenile chinook salmon during migration past sampling site in Snake River, 1964–65*

Year	Length of fish at stage of migration					
	Early [1]			Late [2]		
	Fish	Mean	Range	Fish	Mean	Range
	Number	*Mm.*	*Mm.*	*Number*	*Mm.*	*Mm.*
1964	264	74.5	56–100	220	112	91–135
1965	125	69.3	46–90	124	112	96–125

[1] March through mid-May.
[2] Mid-May through June.

Coho Salmon

The introduction of 375,000 juvenile coho salmon into the Snake River in 1964 provided an

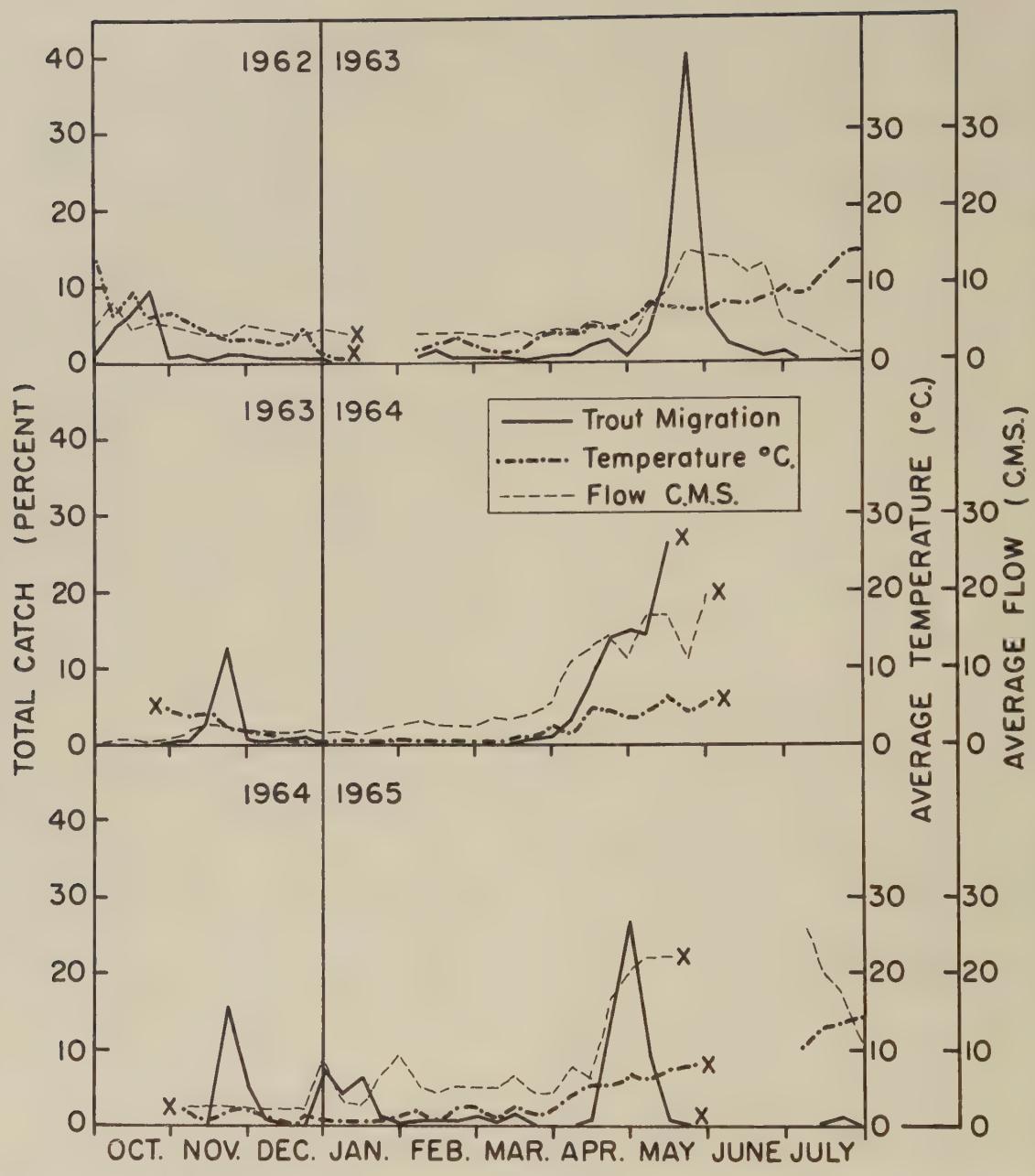

FIGURE 9.—Timing of migration of juvenile rainbow trout to Brownlee Reservoir from Eagle Creek in relation to water temperature and flow, 1962–65 (x indicates period of no data).

opportunity to study the migration of a nonindigenous species. These fish were obtained from a hatchery in the lower Columbia River, transported 120 km. above the reservoir, and released from March 15 to 30 in water that averaged 9.4° C. They did not appear in the Snake River trap until mid-April (fig. 11). The run peaked in mid-May and ended in early June.

The mean lengths of trap samples of coho salmon increased throughout the migration. Migrants averaged 112 mm. (71–140 mm.) early in the season; by the end of the migration period they averaged 131 mm. (110–166 mm.).

Sockeye Salmon

About 473,000 sockeye salmon fingerlings were released in 1965 in the Snake River 88 km. above

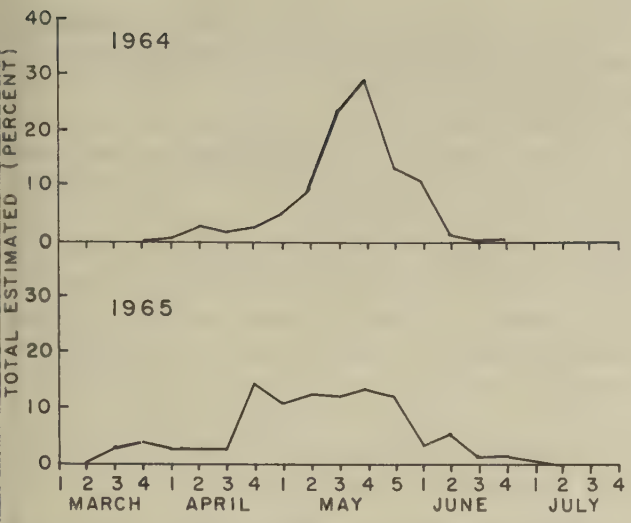

FIGURE 10.—Timing of migration of juvenile hatchery-reared fall chinook salmon (age-group 0) to Brownlee Reservoir from the Snake River, 1964–65.

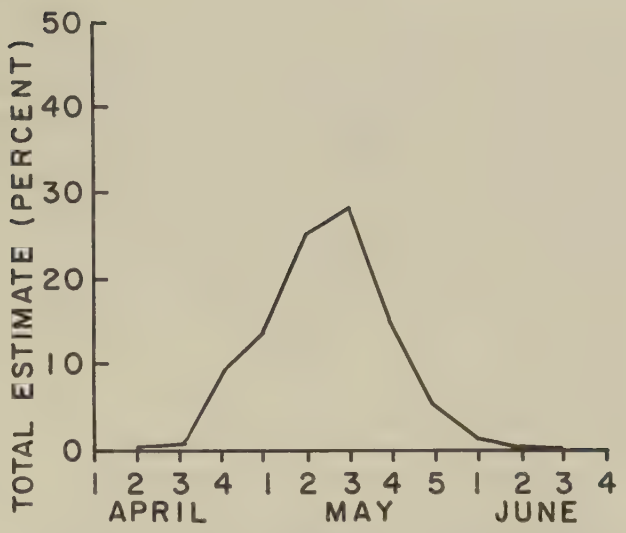

FIGURE 11.—Timing of migration of juvenile hatchery-reared coho salmon from the Snake River to Brownlee Reservoir, 1964.

the reservoir. These fish were reared from eggs obtained in the fall of 1963 from Babine Lake, British Columbia. The eggs were eyed at a hatchery at Maurice Lake, British Columbia, and transported to Leavenworth National Fish Hatchery in Washington, where they were reared until their release in 1965. Releases of 20,000 to 30,000 fish were made 5 days each week from March 15 to April 8, 1965; river water temperatures averaged 9.8° C. The sockeye salmon moved rapidly downstream; the first migrants were recovered within 2 days after the initial release. Peak migration was during the first week of April (fig. 12); by mid-April the migration was nearly complete. Sockeye salmon migrants averaged 121 mm. long (86–175 mm.).

UPSTREAM MOVEMENTS OF JUVENILE CHINOOK SALMON

A late group of chinook salmon fingerlings appeared at the Snake River trap near the end of June or in early July of each year. Because the migrations of fall- and spring-run chinook salmon were essentially completed by this time, the origin of these fish was of interest. Their length was similar to that of age-group I fish from the Weiser River, but examination of their scales revealed that they were fingerlings of age-groups O and I. Growth patterns on their scales showed an area of rapid growth at the margin typical of fish from the reservoir. This scale structure indicated they had moved upstream from the reservoir. This movement was confirmed in 1963 when 12 fin-clipped individuals were caught that had been marked as emigrants from Eagle Creek in the fall of 1962. In 1964, 2.7 percent of the fish captured from this July migration were fall chinook salmon that had been previously tagged and released in the upper reservoir.

According to Durkin et al. (1970), this upstream movement of fish into the Snake River may be related to the environment of the reservoir. The reservoir was rapidly filled early in the 1963 season, and, except for a minor drawdown of 3 m. in May, it was at full pool. Some Eagle Creek fish moved up the reservoir in 1963, possibly because surface currents frequently moved toward the upstream end of the reservoir. Late arrivals may have been attracted upriver by the relatively cooler, oxygenated water as the smolting phenomenon (Hoar, 1963; Conte, Wagner, Fessler, and Gnose, 1966) attenuated and reservoir temperature and oxygen conditions deteriorated (Ebel and Koski, 1968). As the river temperature increased to 20° C., the fish returned to the reservoir. In 1964, when the surface level of the reservoir was lower, Eagle Creek fish were not captured in the Snake River; however, recovery of fall chinook salmon that had been marked and released in the upper reservoir again suggested an upstream response to cooler water.

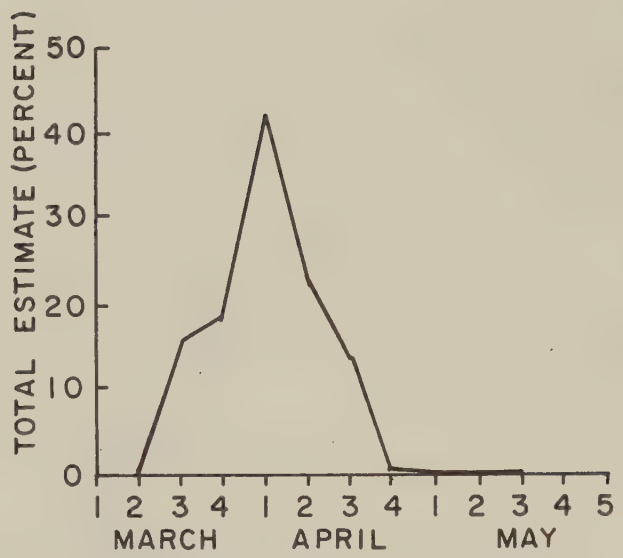

FIGURE 12.—Timing of migration of juvenile hatchery-reared sockeye salmon from the Snake River to Brownlee Reservoir, 1965.

ESTIMATES OF IMMIGRATION

Recruitments by age-group and population were estimated each year from data on release and recapture of marked fish. Estimated recruitment (N) was obtained by dividing the recaptures of marked fish (R) into the number of marked fish released (M) and multiplying by the catch (C).

In 1962, personnel of the Idaho Department of Fish and Game working upstream from the Bureau's migrant-dipper trap marked fall chinook juveniles and released them in the Snake River. These marked fish were used for the 1962 estimate. The marked fish group far exceeded the total catch of the migrant dipper. As a result, a single estimate was made for the Snake River population over the entire season. The 1962 estimate of recruitment for Weiser River chinook salmon was based upon the total catch by the scoop traps of the Idaho Department of Fish and Game and the estimated efficiency of these traps.

In 1963–65, the Snake and Weiser River fish that passed our trap were estimated each week and the values summed to yield the estimated total immigration. Fish for marking were obtained from the migrant dipper catches.

It was sometimes necessary to supply information by extrapolation when reliable data were lacking. When data on catch, recovery of marked fish, or marked fish released were unreliable or lacking, reliable data for 1 or 2 weeks preceding, bracketing, or following were used to supply an approximation of the needed data.

Studies on fish distribution in the Snake River in 1964 indicated that fingerling salmon were more concentrated near the surface during the day than at night (Monan, McConnell, Pugh, and Smith, 1969). Moreover, the increased length of louver leads in 1965 accentuated the difference between the percentage of the migration captured by the traps by day and by night. This difference necessitated the use of two catch figures in estimating the 1965 recruitments. Table 9 shows yearly differences in the ability of the migrant dipper traps to capture fish during the peak of migration.

SNAKE AND WEISER RIVERS

The number of juvenile native chinook salmon that entered Brownlee Reservoir after 1962 decreased each year. One of the reasons was that the adult spawners were intercepted and diverted to hatcheries downstream from Brownlee Dam. Our highest estimate of recruitment was in 1962 when 529,000 young chinook salmon entered from the Snake River (table 10); these fish were offspring of adults that had been transported past the dam and spawned in the fall of 1961. The highest number of juvenile chinook salmon from Weiser River (122,500) was also in 1962; these fish were offspring of spring migrants that had spawned in 1960.

The number of kokanee increased each year; nearly one-half million entered the reservoir in 1965.

Of the hatchery-reared fish released in the Snake River, sockeye salmon had the highest survival to

TABLE 9.—*Ability of migrant dipper traps to capture juvenile salmon during peak migration from the Snake River into Brownlee Reservoir, 1962–65*

Year of migration	Chinook		Coho [1]	Sockeye [1]	Kokanee [1]
	0	I			
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
1962	2.36	(5)	(4)	(4)	(4)
1963	3.56	16.70	(5)	(4)	(5)
1964	8.13	16.85	13.46	(4)	6.2
1965 (a.m.[2])	5.97	(4)	(4)	9.17	6.31
1965 (p.m.[3])	2.35	(4)	(4)	7.10	1.10

[1] All age-group I.
[2] 6:00 a.m.–6:00 p.m.
[3] 6:00 p.m.–6:00 a.m.
[4] Not present in migration.
[5] Not tested.

TABLE 10.—*Estimates of juvenile salmon that entered Brownlee Reservoir from the Snake River system, 1962–65*

Year	Native species			Hatchery-reared species		
	Fall chinook	Spring chinook	Kokanee	Fall chinook	Coho	Sockeye
	Number					
1962 [1]	529,000	122,500	(3)	(3)	(2)	(2)
1963	374,000	15,000	500	(3)	(3)	(3)
1964	(2)	6,800	5,500	111,500	69,000	(3)
1965	(2)	3,200	506,800	162,800	(3)	360,000

[1] Calculated from data supplied in part by Idaho Fish and Game Department.
[2] Negligible numbers.
[3] Not present in migration.

the reservoir, and coho salmon the lowest. Survivals from release point to reservoir were inversely correlated with time spent in the river but not to distance traveled (table 11).

TABLE 11.—*Time in river and survival of hatchery fish from release site to Brownlee Reservoir, 1964 and 1965*

Year and distance	Species of salmon	Median release time	Migration peak	Time in river	Released	Estimate of fish passing collection facilities	Survival
				Weeks	*Number*	*Number*	*Percent*
1964	Coho	Mar. 23	Mid-May	7	375,000	69,000	18.4
120 km.	Chinook	Apr. 1	Mid-May	6	250,000	111,500	44.6
1965	Chinook	Mar. 20	Mid-May	7	592,000	162,800	27.5
88 km.	Sockeye	Mar. 27	Early April.	2	473,000	360,000	76.1

EAGLE CREEK

Estimates of migration from Eagle Creek were based on average efficiencies of the louver facility throughout the year (table 12). In 1962, the average efficiency was 10.2 percent but the louver was selective for larger fish. Alteration of the structure in 1963 increased the efficiency to 57.5 percent and eliminated selectivity. Straightening of the river channel above the louver in 1964 provided a straighter angle of approach for the current and further increased the efficiency of the louvers to 91.3 percent during the fall migration. In the spring of 1965, efficiency was less (85.2 percent) as a result of ice and high flows, which created currents that varied in velocity and direction of approach across the face of the louver.

Juvenile fish that entered the reservoir from Eagle Creek in 1962–63 (table 13) were progeny of native adults that were transported around Brownlee Dam in 1960–62. Thereafter natural production in the creek declined markedly because the policy of passing fish changed. Juvenile migrants in 1964–65 were primarily from adults that were surplus to hatchery needs and were transported from a collection facility at Oxbow Dam (19 km. downstream from Brownlee Dam) to holding ponds near the spawning area. Prespawning fish were held in these ponds until nearly mature and then released into Eagle Creek.

TABLE 12.—*Collection efficiencies of the louver system at Eagle Creek, 1962–65*

Year	Efficiency of collection by period of migration	
	Spring	Fall
	Percent	*Percent*
1962		10.2
1963	14.7	57.5
1964	42.0	91.3
1965	85.2	(1)

[1] Not in operation.

TABLE 13.—*Estimates of juvenile spring chinook salmon that entered Brownlee Reservoir from Eagle Creek, 1962–65*

Year of migration	Estimated recruitment by season and age-group					Total
	Spring migration			Fall migration		
	0	I	II	0	I	
1962	(1)	(1)	(1)	116,000	1,200	117,200
1963	600	13,500	(2)	7,500	(2)	22,300
1964	(2)	6,700	(2)	(2)	(2)	7,200
1965	(2)	(2)	(2)	(1)	(1)	

[1] Not in operation. [2] Negligible numbers.

SUMMARY AND CONCLUSIONS

Movements of juvenile salmon and rainbow trout from tributary streams into Brownlee Reservoir were examined in 1962–65 as part of a study on the effect of a large impoundment on the migration and survival of anadromous fish. Estimated numbers of migrant juvenile salmon were determined by sampling of juvenile fish populations that were en route to the reservoir from the Snake and Weiser Rivers and Eagle Creek, the three tributaries supporting indigenous populations of salmon and anadromous rainbow trout. Juvenile fall and spring chinook salmon, kokanee salmon, and rainbow trout entered the upper reservoir via the Snake River. Hatchery-reared fall

chinook and coho salmon were released in the Snake River in 1964 and fall chinook and sockeye salmon in 1965. Migrations from Eagle Creek near the lower end of the reservoir included native spring chinook salmon and rainbow trout.

Progeny of spring chinook salmon from the Weiser River were fish of age-group I that ranged from 94 to 165 mm. long. This migration began before but partially overlapped a migration of fall chinook juveniles from the Snake River. The migration usually peaked in late April and early May. Estimated numbers of fish were: 1962—122,500; 1963—15,000; 1964—6,800; and 1965—3,200.

The migration of juvenile fall chinook salmon (age-group O) from the Snake River began in mid-April, peaked in mid-May, and was almost complete by mid-June. The fish were 33 to 103 mm. long. Estimated recruitments to Brownlee Reservoir in 1962 and 1963 were 529,000 and 374,000. Because few fish were passed above Brownlee Dam after 1962, migrations of wild fish in 1964–65 were negligible.

Migrant salmon from Eagle Creek were of wild populations of spring chinook salmon. The principal migration of juvenile chinook salmon (age-group 0; 53–125 mm.) was in the fall as irrigation decreased and water flows correspondingly increased. Temperatures ranged from 0° to 13° C. A lesser migration of age-groups 0, I, and II (45–168 mm.) occurred in the spring. Estimated recruitments from Eagle Creek were: 1962—117,200 (fall migration only); 1963—22,300; and 1964—7,200.

Native juvenile kokanee salmon (70–155 mm.) were observed in the Snake River each year in June and July, except in 1962. Their migrations were relatively short; most fish migrated in a 1-week period in late June or early July. Estimated recruitment of this species was 500 in 1963, 5,500 in 1964, and 506,800 in 1965.

Juvenile rainbow trout migrating from the Snake River and Eagle Creek were wild steelhead trout and wild and hatchery-reared rainbow trout. The Snake River populations (95–382 mm.) migrated in the spring from mid-March to late July, peaking from mid-April to mid-May. Juvenile trout, 52–285 mm. long, migrated from Eagle Creek in the fall and spring, but the principal movement coincided with high spring flows.

Juvenile fall chinook salmon, reared in a hatchery (age-group 0; 46–135 mm. long), were released in the Snake River above the reservoir during March and April, 1964–65. Some moved downstream past the trapping site within 3 days after release, but the migration peaked in mid-May, which was comparable to native migrations. The migration ended in late June in 1964 and in early July in 1965. Of 250,000 juvenile fall chinook salmon released in 1964, 111,500 were estimated to have entered the reservoir. In 1965, the estimated recruitment was 162,800 of the 592,000 fish released.

Hatchery-reared coho salmon yearlings (71–166 mm.) released in middle to late March 1964, migrated slowly; they appeared at the trap site 4 weeks after the first release, peaked during the first week of May, and continued to migrate until mid-June. Of the 375,000 coho salmon released, 69,000 entered the reservoir.

Hatchery-reared sockeye salmon (86–175 mm.) appeared at the Snake River trap 2 days after their release in mid-March; the migration peaked in the first week of April and was complete by the end of April. An estimated 360,000 of 473,000 fish released entered the reservoir.

Survival to the reservoir of hatchery-reared salmon varied inversely with time spent in the Snake River but was not related to distance of planting site above Brownlee Reservoir.

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DISTRIBUTION AND MOVEMENT OF JUVENILE SALMON IN BROWNLEE RESERVOIR, 1962–65

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ABSTRACT

Juvenile salmon—chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), and sockeye and kokanee (*O. nerka*)—were studied. Their rates and direction of movement, spatial distribution, and successful passage to the outlet varied in relation to surface currents, water temperature, and dissolved oxygen concentrations.

Some juvenile salmon stayed in Brownlee Reservoir through the summer, fall, and early winter; the percentage varied between years. The percentages were highest in years with high water level and retarded, disoriented flows during the spring migration. Salmon that held over eventually concentrated in rather restricted areas of the reservoir through the summer and early fall, owing to high epilimnion temperatures and to low concentrations of dissolved oxygen that extended into the epilimnion from the hypolimnion.

When the water level was low and reservoir currents were oriented downstream, loss of orientation by juvenile salmon was least and movement through the reservoir was most rapid. These reservoir conditions varied, but salmon populations that migrated early in the year were most likely to encounter them.

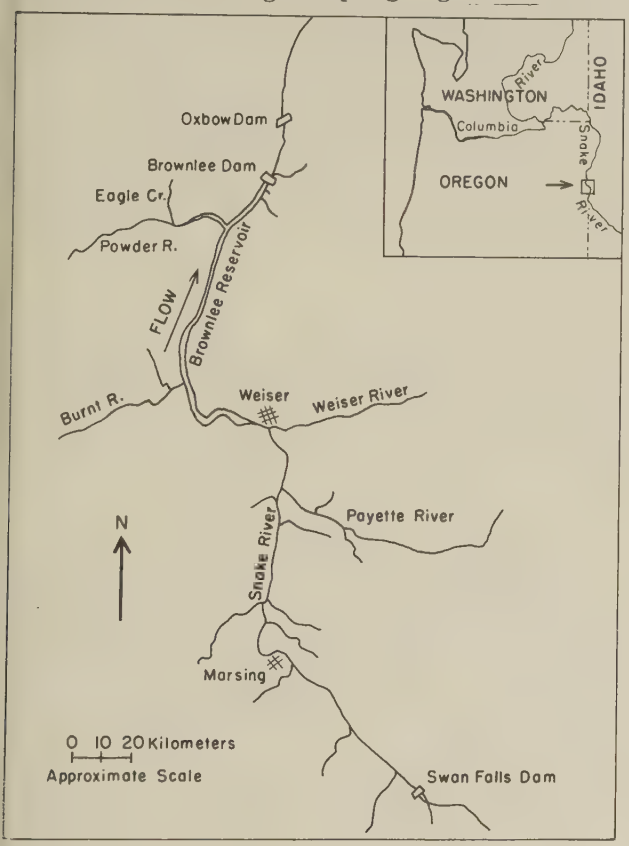

FIGURE 1.—Brownlee Reservoir, Snake River, and major tributaries.

The completion in 1958 of Brownlee Dam on the middle Snake River (Soule, Heikes, Mitchell, and Schaufelberger, 1959) created a long, narrow reservoir along the path of migrating Pacific salmon (genus *Oncorhynchus*) and anadromous rainbow trout (steelhead) *Salmo gairdneri* (fig. 1). At full pool the impoundment is 92 km. long, less than 0.8 km. wide, and nearly 92 m. deep. The upper 24-km. of the reservoir is relatively shallow, slow moving, and forms a river-run impoundment. The lower 68 km., which thermally stratifies, lies within an arid mountainous terrain. Powder River Arm, a prominent appendage on the Oregon side, joins the reservoir 17 km. above the dam and extends westward for 15 km. The upper 5 km. of the arm forms a wide, shallow, unstratified pond when the reservoir is full. Juvenile salmon enter the reservoir from the Snake and Powder Rivers en route to the sea.

When Brownlee Reservoir was completed, detailed knowledge was lacking on the passage of Pacific salmon and steelhead trout through large reservoirs; therefore, BCF (Bureau of Commercial Fisheries) conducted detailed research at Brownlee in 1962–65. These studies covered native stocks of steelhead trout, spring and fall chinook salmon (*O. tshawytscha*), and kokanee (landlocked sockeye salmon, *O. nerka*) in addition to

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hatchery-reared fall chinook, sockeye, and coho (*O. kisutch*) salmon. The research, which began in the spring of 1962, consisted of five studies: (1) limnology of the reservoir system (Ebel and Koski, 1968), (2) upstream migration of adult chinook salmon through the reservoir (Trefethen and Sutherland, 1968), (3) migration of juvenile salmon and trout into the reservoir (Krcma and Raleigh, 1970), (4) distribution and movement of juvenile salmon in the reservoir (this report), and (5) migration of juvenile salmon and trout from the reservoir (Sims, 1970).

Our report gives an account of movements and distributions of the juvenile salmon in relation to their environment. Data on the movements of juvenile steelhead trout were difficult to analyze and report, as we were unable to clearly distinguish them from the nonanadromous wild and hatchery-reared rainbow trout that were also in the reservoir.

EQUIPMENT AND PROCEDURES

To obtain the desired information, it was necessary to sample the juvenile fish in the lower 68 km. of the reservoir. This sampling involved both gear and marking efforts.

FISHING EQUIPMENT

Studies had indicated that four types of fishing equipment were needed to capture juvenile fish: floating traps, gill nets, purse seines, and two-boat trawls. These, together with the fingerling collection facility (skimmer net) of the Idaho Power Company 1.5 km. above the dam, provided basic data on the movement of juvenile salmon within the reservoir. The sampling equipment was deployed to intercept migrants in the upper, middle, and lower reservoir from early in the year until late fall (fig. 2).

Floating Traps

Floating traps were the most effective fishing gear for capturing age-group 0 salmon (fig. 3). The dimensions of the trap, mesh size, and fishing methods were similar to those described by Rothfus, Erho, Hamilton, and Remington.[1] From one to seven of these units were used. The traps were tended every other day early in the year and each day between mid-March and early July. Thereafter, as fish became less available, the traps were operated with diminishing frequency and in most years were removed by late July.

Gill Nets

The number of gill net stations fished depended on the water level and its effect on the length of the reservoir. At each site, two or three parallel sections of multifilament net, 30 m. long by 4.5 m. deep, were fished at predetermined depths in a manner similar to that described by Rees (1957). The mesh sizes were 1.9, 2.5, 3.1, 3.8, 5.1, and 6.3 cm. stretched mesh, of which the 2.5- to 3.8-cm. sizes were most effective. The nets were most efficient on salmon over 90 mm. fork length and at night.

Purse Seines

Two purse seines (Durkin and Park, 1967) were used as mobile sampling gear on fish concentrations throughout the limnetic environment of the reservoir. One of the seines was 180 m. long and 10.5 m. deep; the other was 210 m. long and 16.5 deep. Both were set from a barge. Purse seines were used in the main reservoir during spring and early summer and in the Powder River Arm during fall.

Two-Boat Trawls

Surface trawls (Johnson, 1956) were used to locate concentrations of salmon and to determine their relative abundance. The trawls were 3.0 m. high, 5.4 m. wide at the mouth, and 7.8 m. long.

MARKING

Various types of marks were placed on captured juvenile fish for identification at recapture. The type of mark depended on the size of fish. Fish less than 100 mm. long were marked with vinyl thread tags (developed by personnel of the Fish Commission of Oregon). A jaw tag clamped to the left mandible marked the fish (100 to 250 mm. long); fish over 250 mm. had a plastic dart tag. Color coded tattoos, used in 1962, were discontinued when the vinyl thread tag became available. Other groups of fish were marked by clipping fins before they entered the reservoir (Krcma and Raleigh, 1970).

[1] Lloyd O. Rothfus, Michael Erho, J. A. R. Hamilton, and Jack D. Remington. 1964. A study of reservoir rearing of coho salmon in Lake Merwin, Washington. State Wash. Dep. Fish., Res. Div., 18 pp. (Processed.)

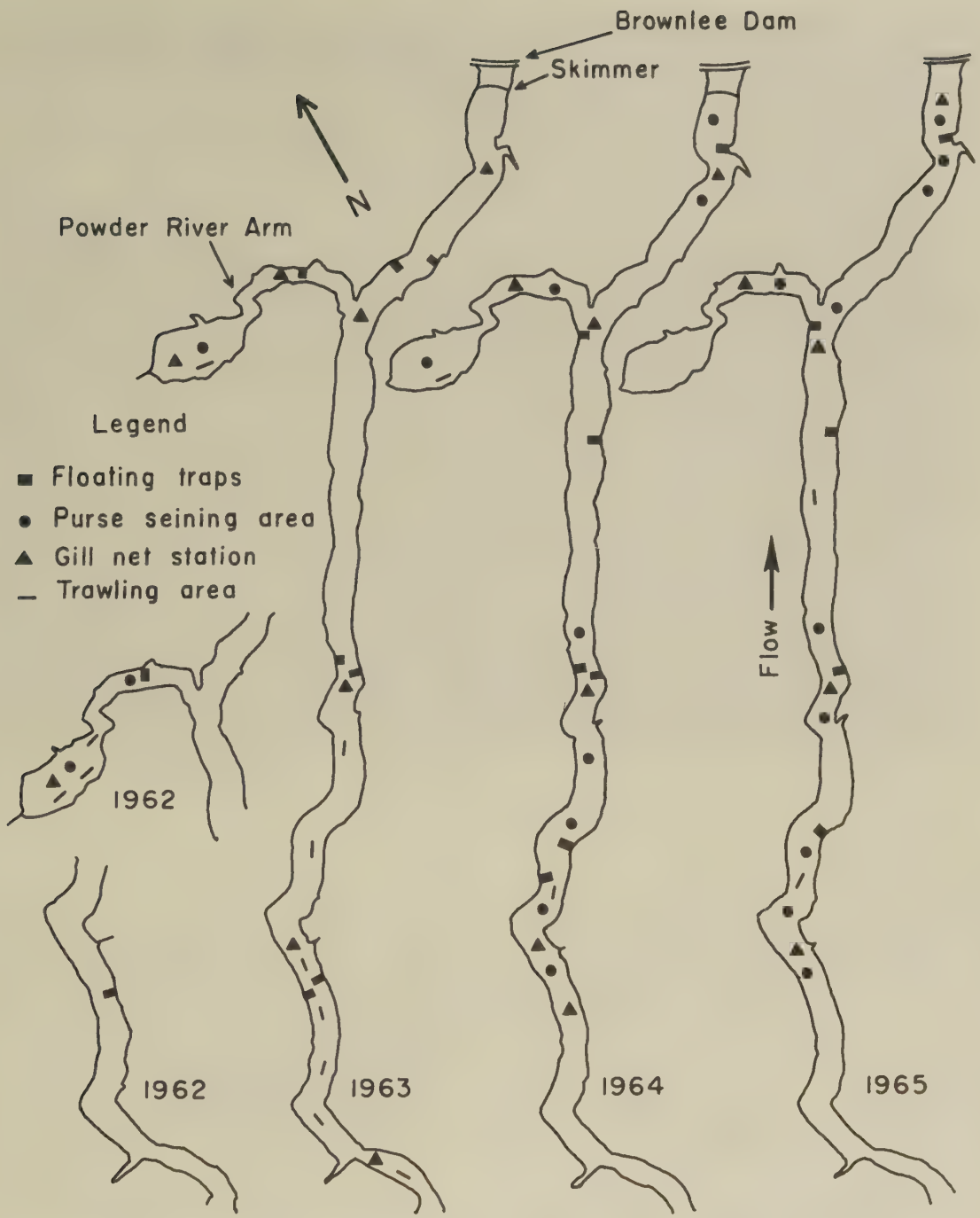

FIGURE 2.—Location of sampling areas and types of fishing gear used in Brownlee Reservoir, 1962–65.

FIGURE 3.—Floating trap used to capture juvenile salmon moving near the shore. Salmon were diverted to the trap by a lead extending from the shoreline.

A combination of length-frequency ranges and the above marks identified specific populations and individual fish and, thus, yielded data on direction and rate of movement, spatial distribution, growth, and survival of the populations of salmon that entered the reservoir.

Upon capture, the fish were anesthetized, measured (fork length) to the nearest millimeter, examined for marks, and tagged if not previously marked. Scales for age determination were taken each month from a sample of up to 10 fish in each 5-mm. length group in the catches. All fish were released near the capture site.

THE ENVIRONMENT OF THE RESERVOIR

Apparently, the conditions exerting the greatest effect on the environment of Brownlee Reservoir were the size and timing of the annual reservoir drawdown and fillup and the volume of flow through the impoundment. Water level of the reservoir, filling, spillway discharge, and flow varied considerably during the 4-year study (fig. 4). The drawdown was least (6.4 m.) in 1963 and greatest (28.3 m.) in 1965. Drawdown typically began in December or January. Filling began each year in early April except in 1965 when it was delayed until mid-May. Filling was nearly complete by late June 1962, mid-April 1963, mid-June 1964, and mid-June 1965. The extent of drawdown or fill determined the length of the reservoir, and the time of filling determined the quality of the water through which the fish migrated.

SURFACE CURRENTS

The volume of inflow and outflow, together with the water level of the reservoir, determined the orientation and stability of currents and the velocity of flow. Figure 5 shows typical currents under different reservoir conditions.

The stability, velocity, and orientation of the reservoir surface currents varied considerably over the study years (1962–65). Surface currents near

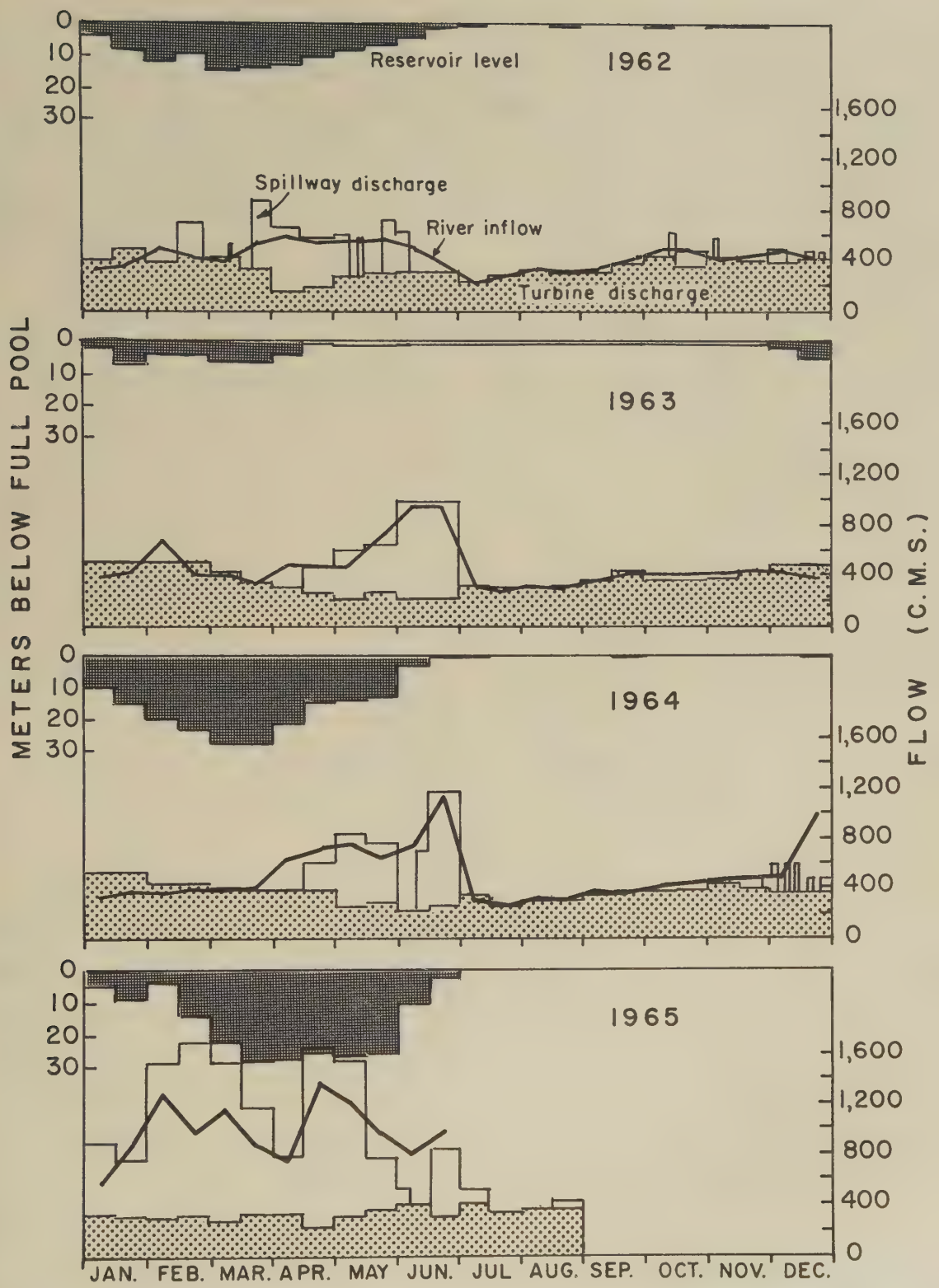

FIGURE 4.—Semimonthly averages of reservoir water level, turbine and spillway discharges, and Snake River flow into Brownlee Reservoir, 1962–65. Flow is in cubic meters per second.

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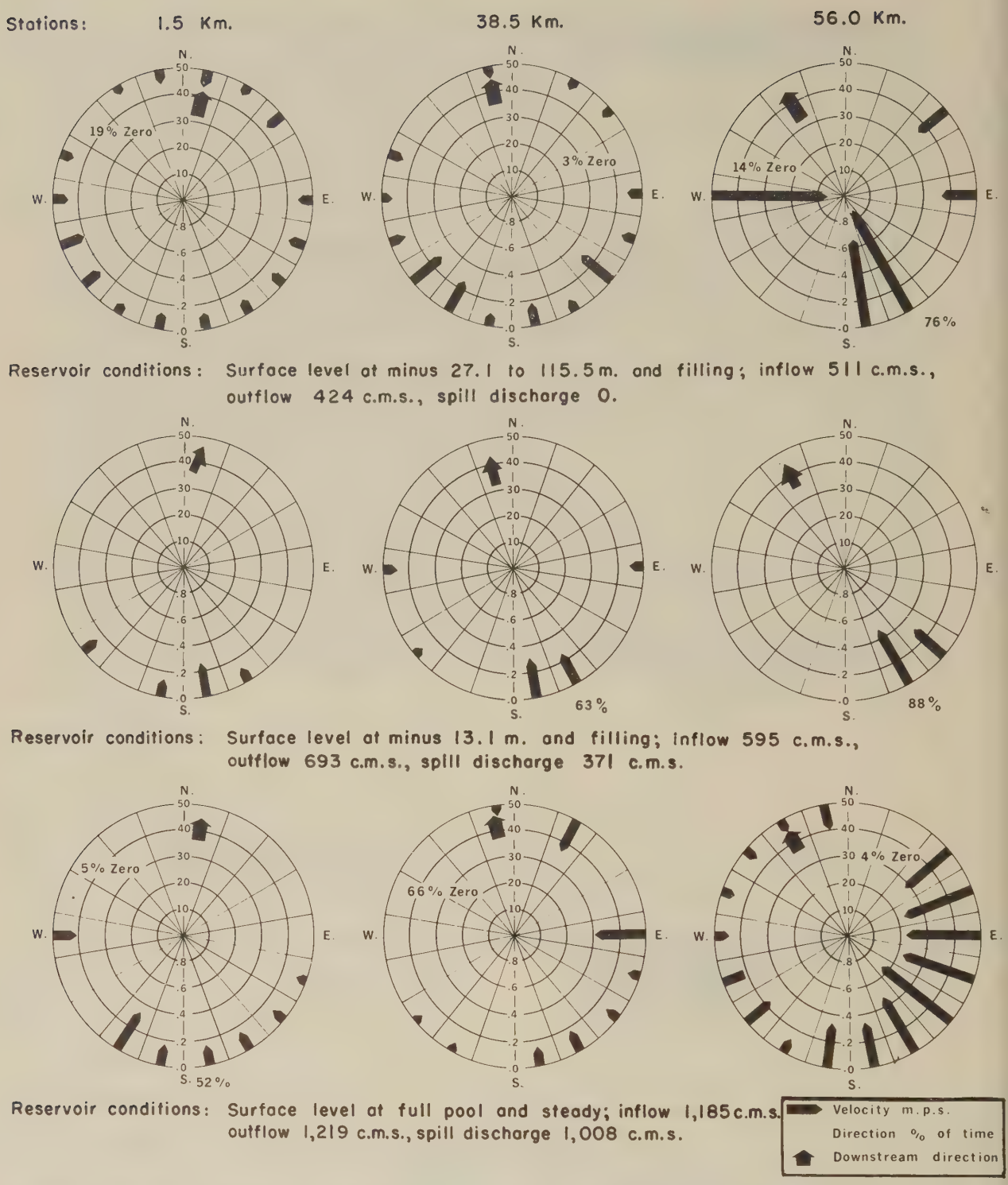
Stations: 1.5 Km.
38.5 Km.
56.0 Km.
19% Zero
3% Zero
14% Zero
76%
Reservoir conditions: Surface level at minus 27.1 to 115.5 m. and filling; inflow 511 c.m.s., outflow 424 c.m.s., spill discharge 0.
63%
88%
Reservoir conditions: Surface level at minus 13.1 m. and filling; inflow 595 c.m.s., outflow 693 c.m.s., spill discharge 371 c.m.s.
5% Zero
66% Zero
4% Zero
52%
Reservoir conditions: Surface level at full pool and steady; inflow 1,185 c.m.s. outflow 1,219 c.m.s., spill discharge 1,008 c.m.s.
Velocity m.p.s.
Direction % of time
Downstream direction

FIGURE 5.—Direction (percentage of time, indicated by scale between center and upper margin of each figure) and average velocity (m.p.s. scale between center and lower margin) of currents recorded at 3-m. depth in Brownlee Reservoir. Direction of current reads toward point of wedge. Percentages of time (if any) during which no flow was detectable are given within each circle; when flow was in a particular direction more than 50 percent of the time the percentage is given outside of the circle. Adapted from Ebel and Koski (1968).

the dam were affected mainly by the presence or absence of spillway discharges even when the reservoir level was down 27.1 to 15.5 m. (fig. 5). Surface currents in the middle and upper sections of the reservoir, however, appear to be little affected by spillway discharges. Reservoir level and volumes of flow had the greatest effect on the orientation and stability of the surface currents in these areas (fig. 5).

TEMPERATURE CYCLE

The volume of flow and water level of the reservoir also influenced the characteristics of temperature and oxygen in the impoundment. Figure 6 shows a generalized annual thermal cycle in the reservoir. From January to mid-March, isotherms of 1° to 6° C. were vertically aligned. Horizontal alignment of isotherms began in late March, and thermal stratification developed by early June. A sharp convergence line (not shown in fig. 6) was formed in the upper reservoir in late spring of 1963 when cold, dense river water sank below the warmer surface water (Ebel and Koski, 1968). In late June, the temperatures of the river water and surface water were similar and the line disappeared. By mid-July the entire reservoir was usually stratified with well-defined epilimnion, thermocline, and hypolimnion. In late summer, water temperatures ranged from 5° C. in the hypolimnion to as high as 24° C. at the surface. In mid-October a convergence line was again formed by rapidly cooling water from the Snake River and the thermocline was gradually eroded. Vertical alignment of isotherms began again in early December.

DISSOLVED OXYGEN CYCLE

The dissolved oxygen content of the reservoir followed a similar cycle each year (fig. 7). The reservoir was near saturation and relatively stable from January to mid-March, at which time oxygen concentrations began to decline in the deeper parts. Depletion of oxygen continued through the summer until August when all water below 30 m. had less than 3 p.p.m. In September, the cooler, oxygenated water from Snake River began to sink below the surface of the upper reservoir. By November, most of the water had 7 to 9 p.p.m. of oxygen.

These seasonal changes occurred each year, but with certain differences. In 1965, a drawdown of 28.3 m. and a late filling period caused: (1) late formation of a thermocline, (2) higher average temperatures from top to bottom, (3) lower oxygen concentrations during August and September, and (4) currents that were consistently oriented downreservoir through May. Drawdown was significant in 1964 (26.7 m.), but the filling began earlier and volumes of inflow and outflow were smaller. Temperatures were lower and concentrations of dissolved oxygen were higher in 1964 than in 1965, but conditions were less favorable for fish than in 1962 or 1963. A reservoir drawdown sufficient to allow sustained downreservoir current velocities can prevent a sharply defined convergence line from forming. For this reason, no convergence line formed in the upper reservoir in the spring of 1962, 1964, or 1965.

Generally, the temperatures and dissolved oxygen in the reservoir were within acceptable limits for survival of salmon during their spring migration (March-June). These conditions, however, began to deteriorate by late June and were marginal to restrictive until late September. A more detailed report of the environment was presented by Ebel and Koski (1968).

DISTRIBUTION AND MOVEMENT OF NATIVE STOCKS OF SALMON

Juvenile salmon from four populations were indigenous to Brownlee Reservoir: Two were progeny of spring chinook salmon, one of fall chinook salmon, and one of kokanee. The account of movement and behavior of juvenile salmon while passing through the reservoir environment is presented by species and population.

SPRING CHINOOK SALMON

Offspring of spring chinook salmon enter the reservoir from two areas: the Weiser River, a tributary of the Snake River, and Eagle Creek, a tributary of the Powder River (fig. 1). Migrants from Weiser River must traverse the entire reservoir on their seaward migration, whereas Eagle Creek migrants have less than one-half of the reservoir to negotiate. The two populations also differ in average age, size, and season of entry. Table 1 gives yearly estimates of the numbers of young fish that entered the reservoir in 1962–65.

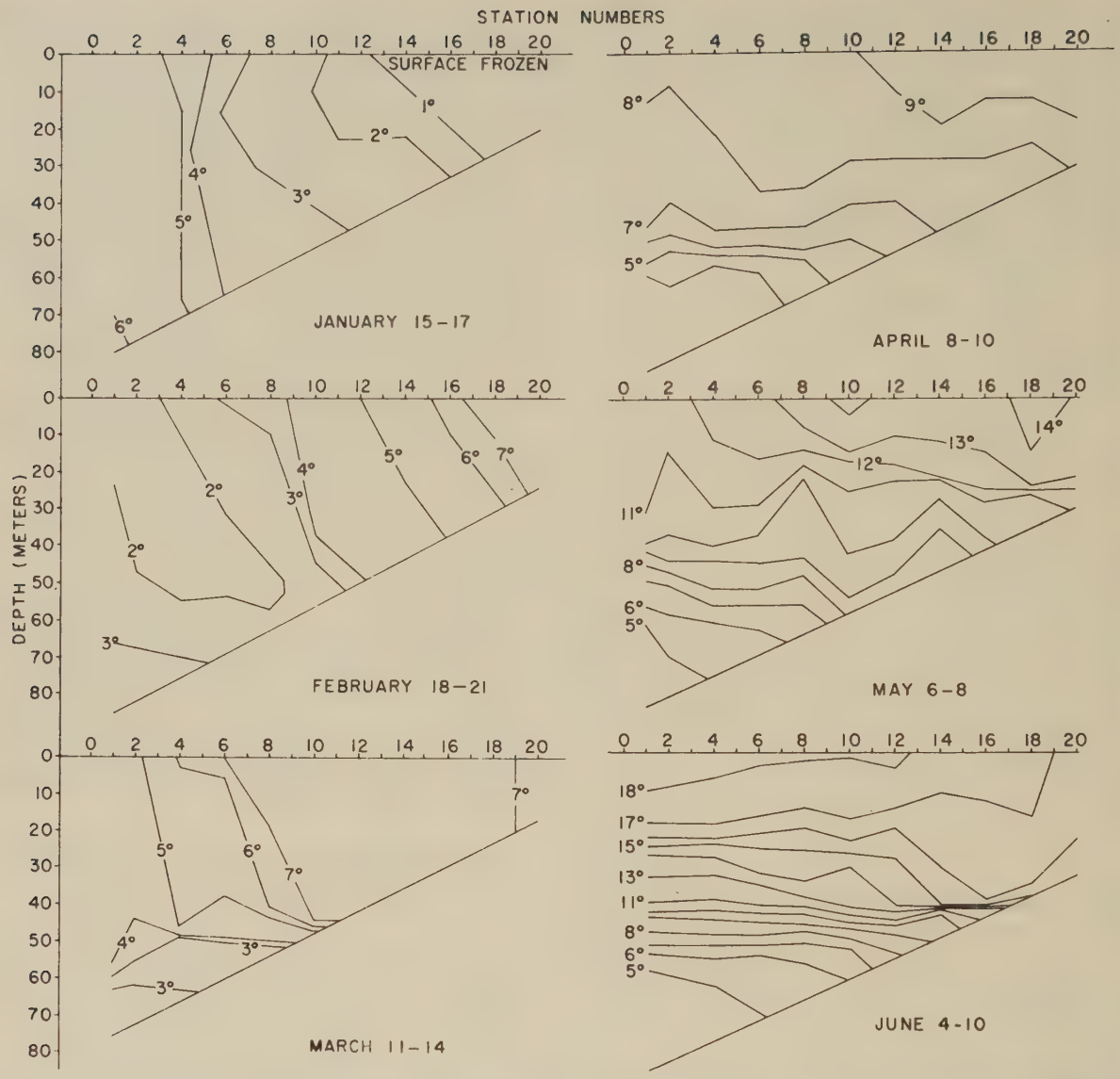

FIGURE 6.—Water temperature profile and stratification cycle at Brownlee Reservoir, 1963, modified from Ebel and Koski (1968).

TABLE 1.—*Estimated numbers of juvenile spring chinook salmon that entered Brownlee Reservoir, 1962–65 (from Krcma and Raleigh, 1970)*

Year	Weiser River origin	Eagle Creek origin				
	Age-group I	Spring migrants			Fall migrants	
		Age-group			Age-group	
		0	I	II	0	I
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
1962	122,500	(1)	(1)	(1)	116,000	1,200
1963	15,000	600	13,500	(2)	7,500	(2)
1964	6,800	(2)	6,700	(2)	(2)	(1)
1965	3,200	(2)	(2)	(2)	(1)	(1)

[1] Not estimated.
[2] Negligible numbers.

Weiser River Population

Spring chinook salmon from the Weiser River, 106 to 176 mm. long, entered the reservoir as yearlings from early April until late June. The migration peaked from late April to early May each year.

Through late May, spring chinook salmon from the Weiser River that were in the reservoir could be distinguished from fall chinook salmon of age-groups O and I on the basis of length; they were longer than age-group O but shorter than age-group I of the fall stock. After late May, as length

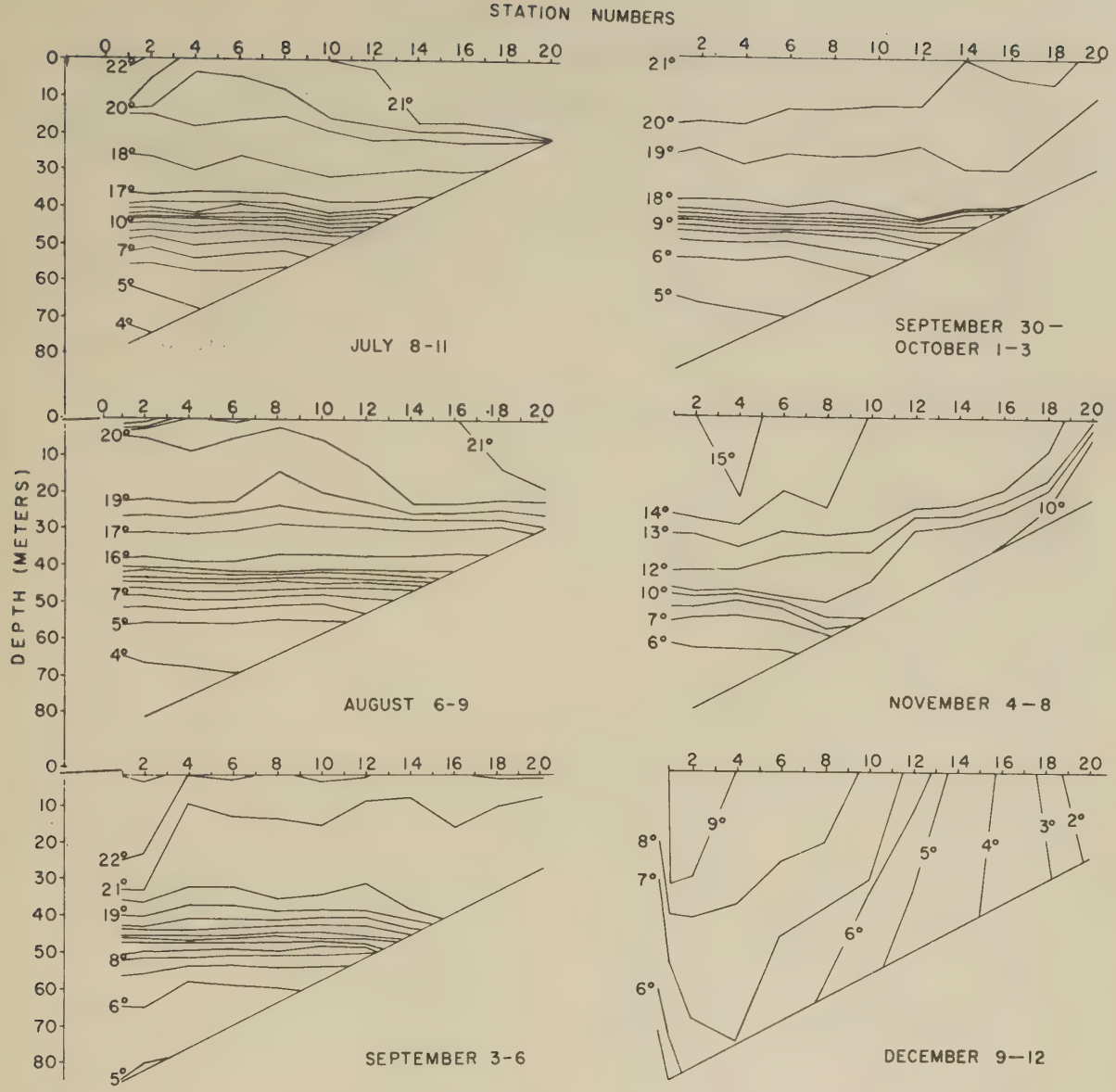

FIGURE 6.—Continued

measurements overlapped, the populations were separated on the basis of marked fish in the catch. By late May, however, the peak of migration from the Weiser River had usually passed through the reservoir.

A comparison of the timing of peak catches in the Snake River above the reservoir and at Brownlee Dam provided rough estimates of the time required for passage through the reservoir—about 2 weeks in 1962 and 3 weeks in 1963 (fig. 8). Differences in flow and length of reservoir between the 2 years appear to account for the more rapid movement in 1962. From early May through early June 1962 the reservoir was drawn down 9 m. and was about 75 km. long. Over the same period in 1963 it was nearly full and 92 km. long (fig. 4). Because of decreased depth and length in 1962, the average movement of the water mass through the reservoir was more rapid and conducive to passage of fish.

On the basis of the comparison of peak catches, the movement through the reservoir of yearling chinook salmon from the Weiser River averaged 6.4 km. per day in 1962 and 4.8 km. per day in 1963. Recapture of 334 marked individuals in 1962 and 1963 indicated that these fish moved through

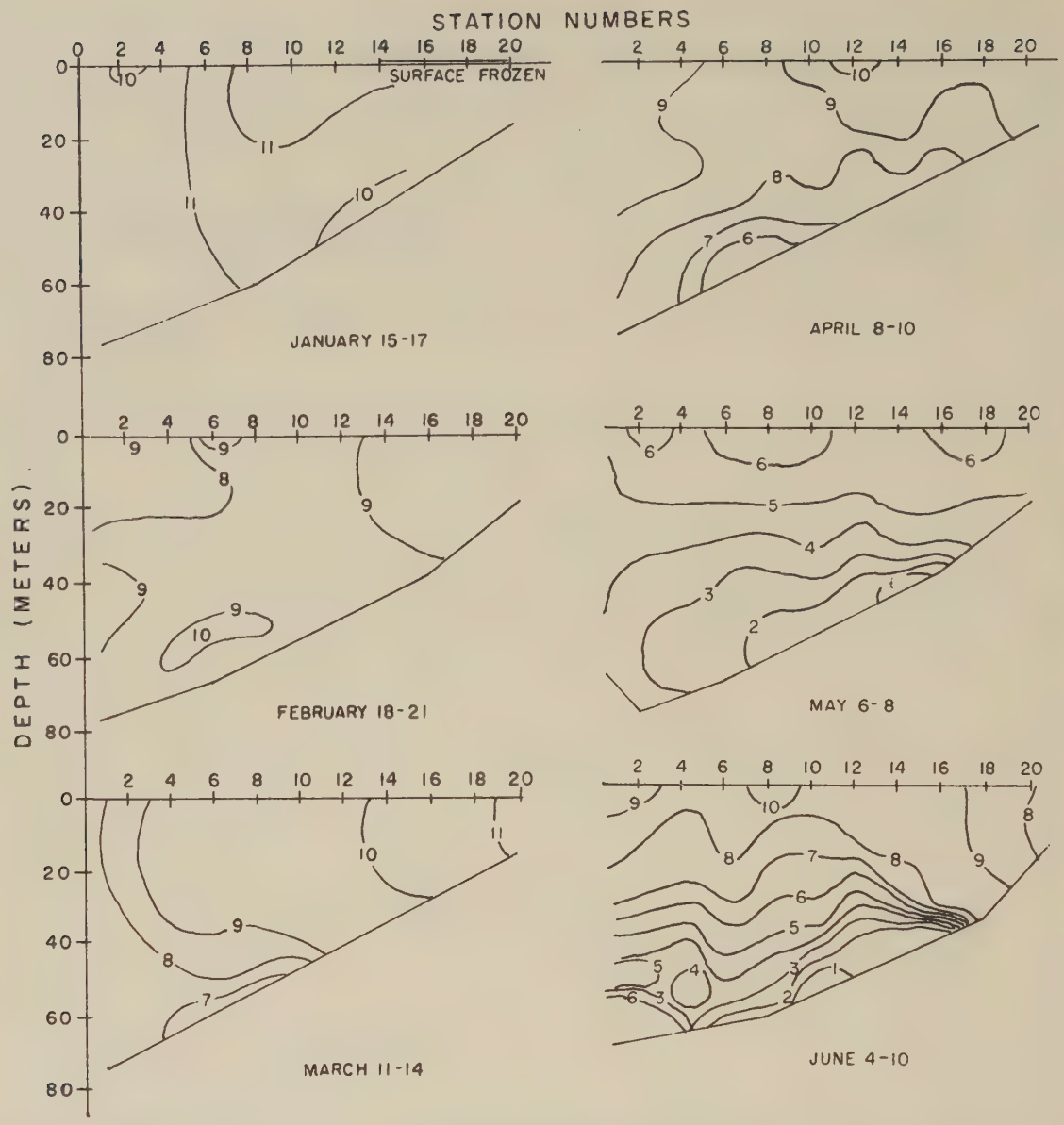

FIGURE 7.—Dissolved oxygen (p.p.m.) profiles from Brownlee Reservoir, 1963, modified from Ebel and Koski (1968).

the reservoir with little wandering and corroborated the estimated rates of movement.

In 1962, about 3,200 fish from the Weiser River population were marked as they were entering the reservoir. Six were recaptured the following spring (1963) in the reservoir. In 1963, about 1,900 fish were marked during their migration into the reservoir; in late June and July, 23 were recaptured in the Snake River. A study of growth patterns on their scales showed that they had returned upstream from the reservoir. These recaptures indicate that some fish of the Weiser River population become disoriented and hold over in the reservoir, but this behavior did not appear to be a major factor in the general movement of this early migrating population of large yearling fish.

In general, the Weiser River chinook salmon passed through a more benign environment in the reservoir than did populations migrating later in the season (figs. 6 and 7).

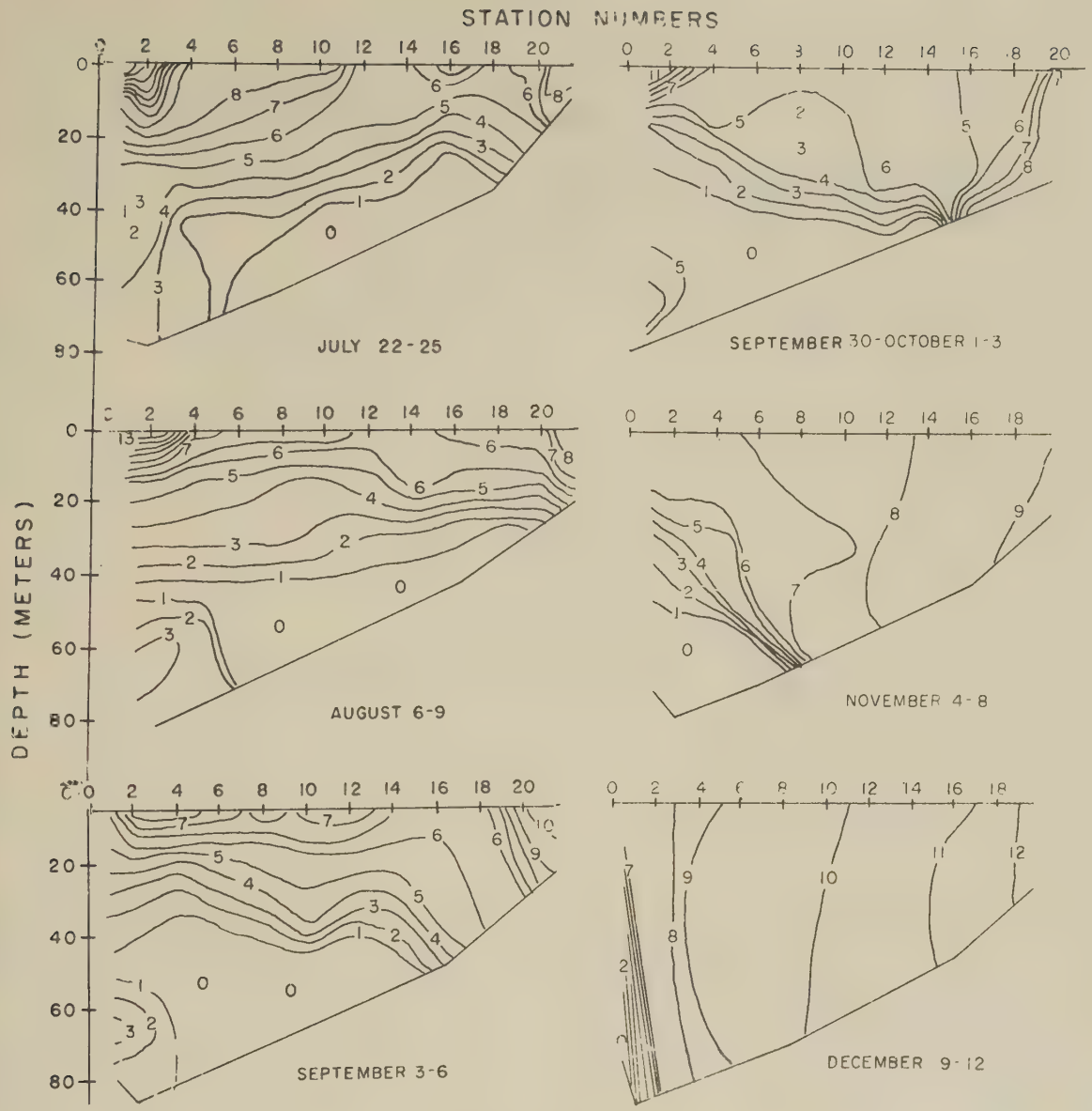

FIGURE 7.—Continued

Eagle Creek Population

The principal migration of spring chinook salmon from Eagle Creek into the reservoir was in the fall and consisted of age-group O fish, 53 to 125 mm. long. This movement was followed by a second lesser migration of age-group I fish, 65 to 138 mm. long, from February to May (Krcma and Raleigh, 1970). Only chinook salmon that had held over from the spring migrations were found in significant numbers in the reservoir at that time of year. These populations were separable by size (fig. 9).

Continuous recovery from the upper Powder River Arm and the main reservoir of marked age-group O fish from the fall migration from Eagle Creek indicated that not all these fingerlings continued to move through the reservoir. Further evidence was obtained by comparing mean lengths of fish caught leaving Eagle Creek with those of fish from the reservoir. Fish that remained in the stream grew little through the fall and winter, whereas those in the reservoir continued to grow.

Incidental movement of Eagle Creek fish from the reservoir began in November, but a sustained

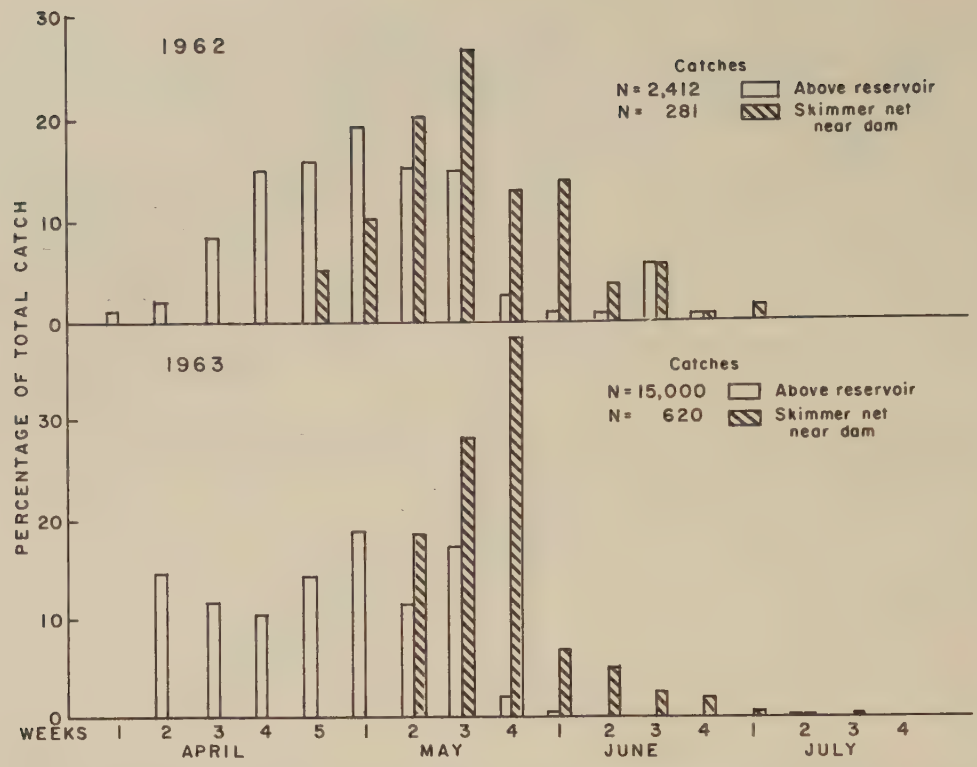

FIGURE 8.—Percentages of the total catch of juvenile spring chinook salmon from Weiser River, taken during different weeks at the upper and lower ends of Brownlee Reservoir, 1962–63.

outmigration did not occur until after the first of the year (Sims, 1970). There were two major migrations of Eagle Creek fish from the reservoir each year; the first consisted of fish that entered the reservoir in the fall and overwintered, and the second consisted of spring migrants that moved directly from the stream to the dam (fig. 10). The first group migrated from the reservoir primarily from late January to April and the second group from late March to June (fig. 11).

We investigated the possibility that the reservoir might be delaying the seaward migration of the fall migrants. Tagging data showed that most fall migrants spent about 3 months in the reservoir, whereas most spring migrants moved through the reservoir in a much shorter time. In 1964 and 1965, groups of Eagle Creek fall migrants were marked, transported around Brownlee and Oxbow Dams, and released in the Snake River. Sampling at Ice Harbor Dam (442 km. downstream from Brownlee) showed that fish released in the river below the dams overwintered in the Snake River and arrived at Ice Harbor Dam at about the same time as the group that passed through the reservoir.[3] It appears, therefore, that Brownlee Reservoir did not unduly delay the fall migration from Eagle Creek and that these fish normally overwinter before going to sea.

Although Brownlee Reservoir did not appear to cause an appreciable delay in the seaward migration of the fall migrants, some fish from Eagle Creek became disoriented in the reservoir under certain conditions. In 1962 and 1964, fish from Eagle Creek moved consistently downstream toward the dam. In 1963, however, a segment of the population moved upreservoir. This movement was proven by capture of 12 marked individuals in the Snake River 4 km. above the reservoir in late June and July 1963. Drawdown of the reservoir exceeded 14 m. in 1962 and 1964 but was only 6.4 m. in 1963. Figures 4 and 5 indicate that these conditions would provide weak downstream currents in 1962 and 1964 but disoriented currents in

[3] Personal communication, Howard Raymond, Fishery Biologist, BCF Biological Laboratory, Seattle, Wash., June 1965.

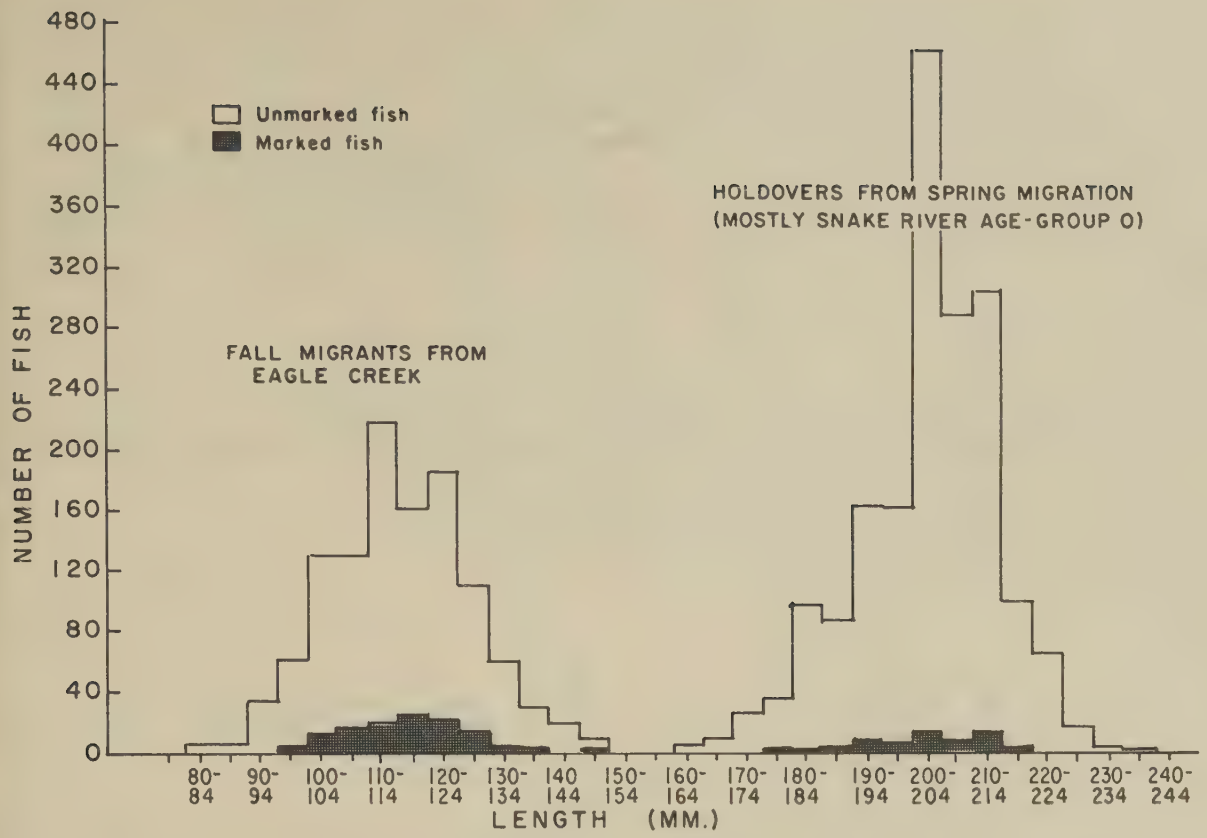

FIGURE 9.—Lengths of juvenile spring chinook salmon from Eagle Creek that entered Brownlee Reservoir in the fall and lengths of holdover chinook salmon from populations that entered in the spring, in samples collected September through December 1962.

1963. We presume that some Eagle Creek fish moved upreservoir in 1963 because of frequent upreservoir currents. The fish that arrived at the upper end of the reservoir in late June and July as the "smolting" condition (Hoar, 1963; Conte, Wagner, Fessler, and Gnose, 1966) was attenuating and reservoir temperature and oxygen conditions were deteriorating (figs. 6–7) may have been attracted upstream by the relatively cooler, oxygenated water of the Snake River.

FALL CHINOOK SALMON OF AGE-GROUP O

Juvenile fall chinook salmon entered the reservoir as age-group O and at a smaller length (33–105 mm.) than other populations. They began their migration from spawning grounds in the Snake River about 120 km. above the reservoir. Table 2 gives estimates of fall chinook juvenile salmon that entered the reservoir.

We studied the offspring of native populations in 1962 and 1963; hatchery-reared juvenile fish from other sources were released in the spawning area for study as they passed through the reservoir in 1964 and 1965.

TABLE 2.—*Estimated numbers of fall chinook salmon that entered Brownlee Reservoir, 1962–65 (from Krcma and Raleigh, 1970)*

Year	Native	Hatchery-reared
	Number of fish	
1962	529,000	(1)
1963	374,000	(1)
1964	(2)	111,500
1965	(2)	162,800

[1] None released.
[2] Negligible numbers.

Juvenile native fall chinook salmon entered the reservoir from late April through June in 1962 and from late April through mid-June in 1963. Mean lengths of age-group O fish in the reservoir were 56 to 85 mm. through the 1962 season and 75 to 195 mm. in 1963.

Peak catches above the reservoir and at the fingerling collection facility near Brownlee Dam

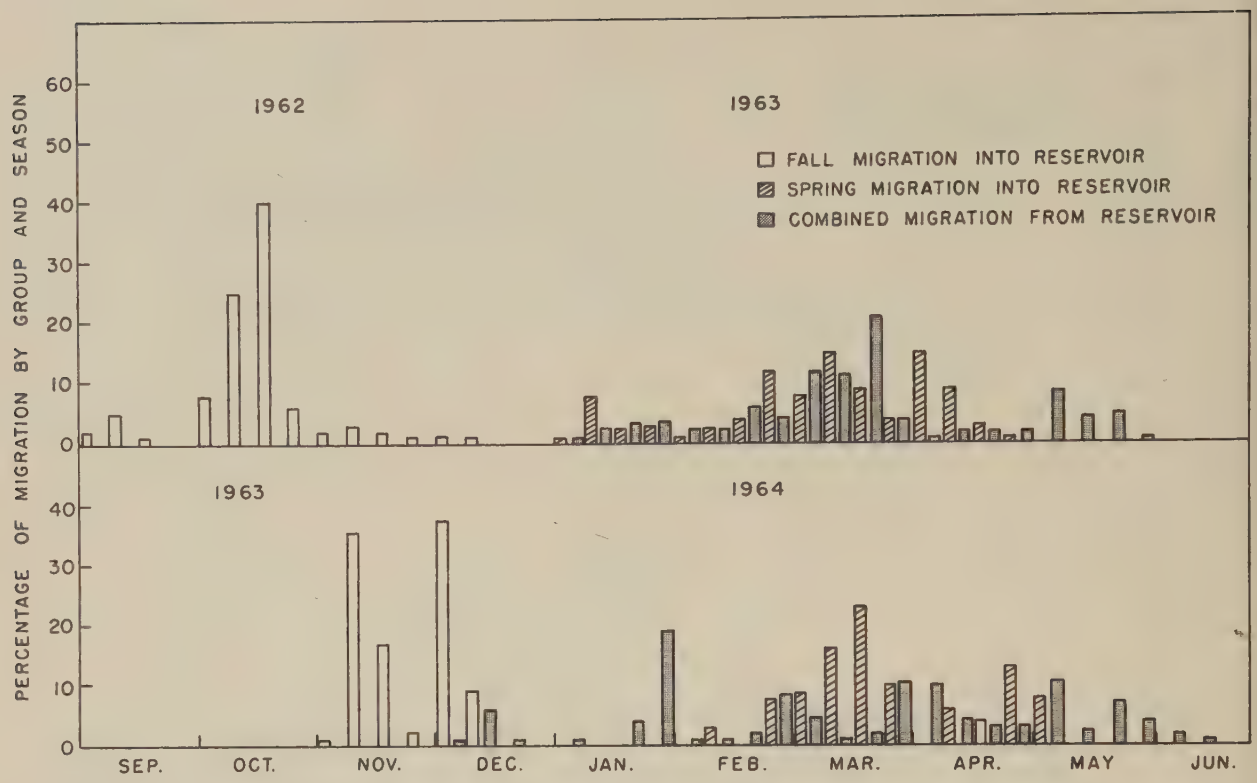

FIGURE 10.—Percentage of total catches of juvenile spring chinook salmon from Eagle Creek that entered and that left Brownlee Reservoir in different months, 1962–64. Fish entering the reservoir were caught in a louver trap at Eagle Creek (Krcma and Raleigh, 1970); fish leaving the reservoir were caught in skimmer net traps in the forebay (1963) or in scoop traps below the dam (1964).

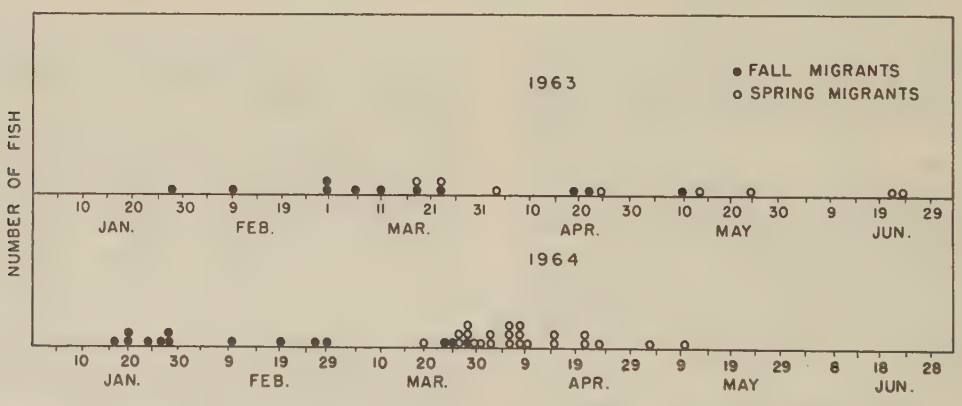

FIGURE 11.—Date of arrival at Brownlee Dam of juvenile spring chinook salmon tagged at Eagle Creek during the fall and spring migrations of 1962–64. Each circle represents one recovery.

showed that juvenile fall chinook salmon passed through the reservoir in about 2 weeks in 1962 and in about 7 weeks in 1963 (fig. 12). Figures 4 and 5 indicate that the currents would have been of low velocity but moderately well oriented downstream during the 1962 migration. In 1963, the migrant fall chinook salmon entered the reservoir a week later than in 1962 (fig. 12). At that time the reservoir was drawn down only 3 m. and was being filled. Although volumes of inflow and outflow were moderate to high, the currents were disoriented (figs. 4 and 5).

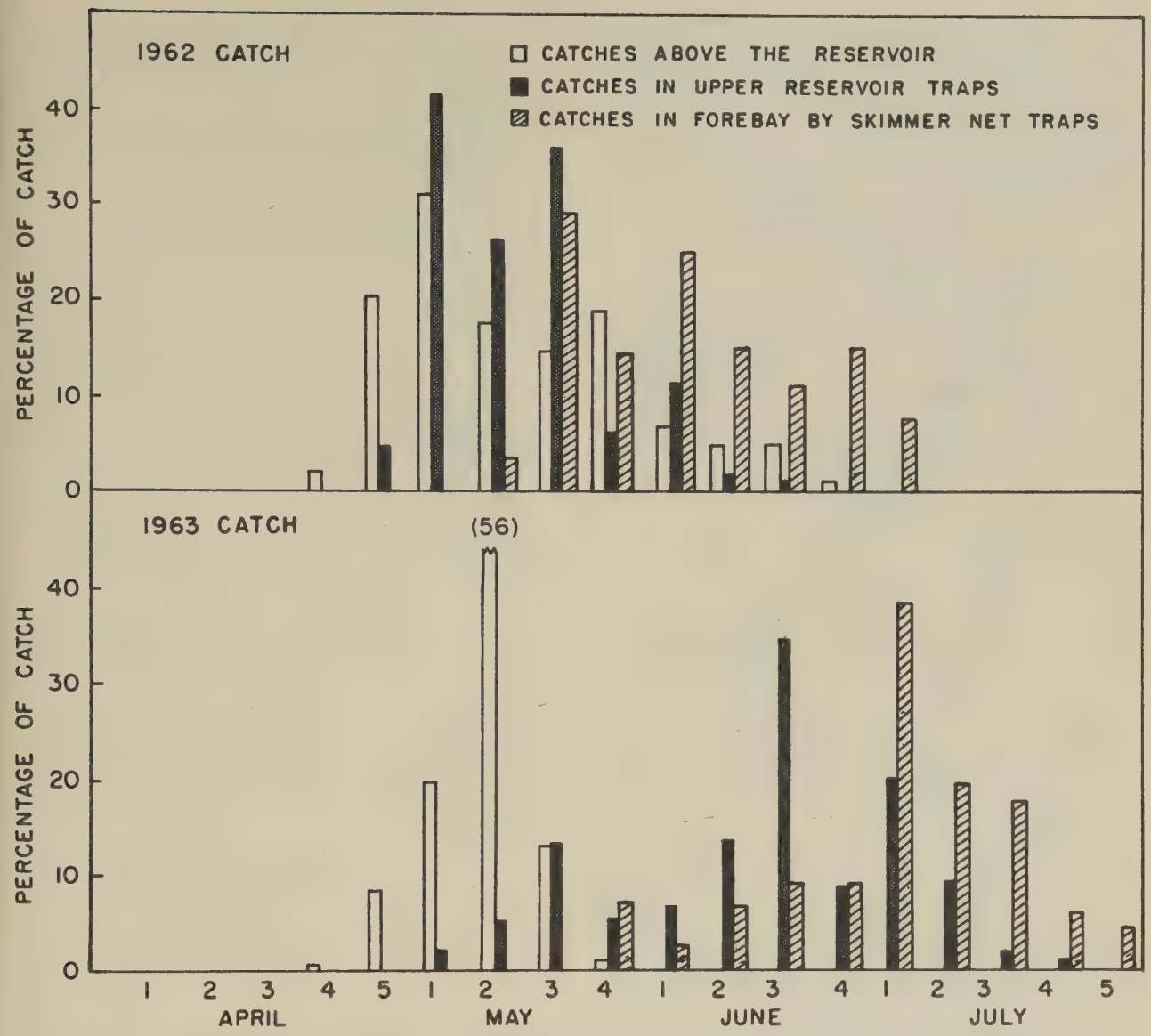

FIGURE 12.—Catches of native juvenile fall chinook salmon in the upper reservoir and at Brownlee Dam, 1962–63.

Trap and surface trawl catches in 1963 indicated that most of the migrants were remaining in the upper reservoir. They were in the Snake River water mass upstream from the point where the colder river water sank below the reservoir surface (Ebel and Koski, 1968; Raleigh and Ebel, 1967). Gill net sampling showed the fish were near the surface of the reservoir through mid-June. By late June, however, they were captured at all depths. At this time the river water began to warm and mix with the reservoir water mass; the convergence line disintegrated, and the juvenile fish began to move through the reservoir. Peak catches by traps in the upper reservoir and at Brownlee Dam showed that after the initial 5-week delay the fish migrated through the reservoir in about 2 weeks (fig. 12).

In 1963, the capture of a number of large fingerlings in the Snake River above the impoundment indicated a pronounced upreservoir movement of young fall chinook salmon (Krcma and Raleigh, 1970). Growth patterns on the scales showed that these fish had lived in the reservoir. The identification of marked fish indicated that most of the fish that moved upstream had migrated from Eagle Creek and the Snake River in the spring of 1963.

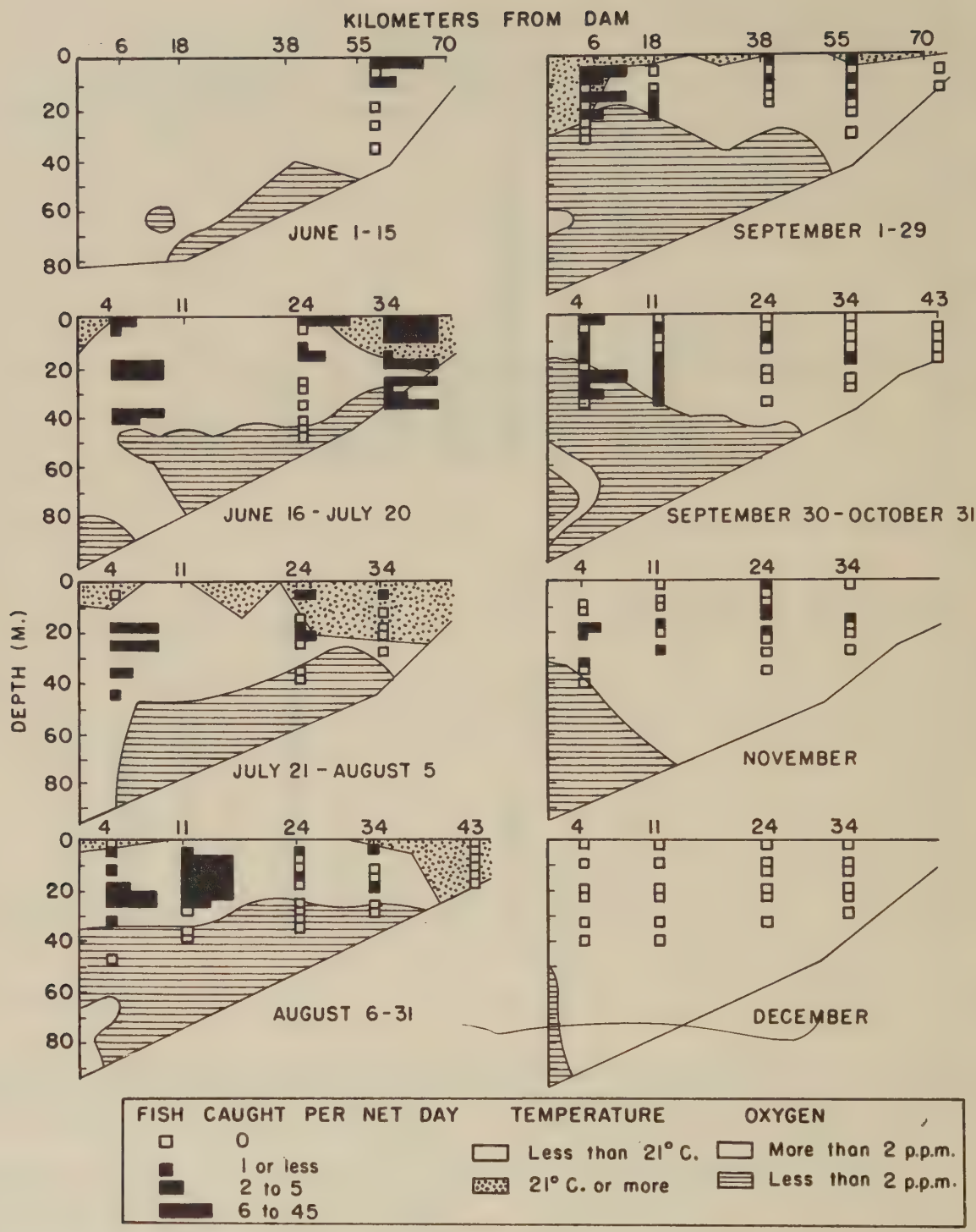

FIGURE 13.—Distribution of juvenile fall chinook salmon in Brownlee Reservoir in relation to critical oxygen and temperature regimes. Fish caught in gill nets in 1963.

We presume that these fish were attracted upstream by the cooler water of the Snake River (14–22° C.), which averaged 2 to 3° C. less than the reservoir. The subsequent downstream migration coincided with an increase in river temperatures to over 18° C. and the breakdown of the convergence line.

In most years, after the migration of smolts ended in late June or July, some chinook salmon remained in the reservoir as holdovers. In 1963, most of the migrants did not leave the reservoir even though the outmigration continued into August (Sims, 1970). The holdover fish were from all salmon populations but were mainly progeny of fall chinook salmon. They were easily distinguished from more recent arrivals by their large size; in addition, some had identifying fin clips or tags.

Gill net catches showed that the holdover salmon had a restricted spatial distribution through the summer and early fall. By late June or early July, surface temperatures exceeded 20° C. and oxygen depletion progressed upward from the bottom. These conditions were especially prevalent in the upper end of the reservoir (figs. 6 and 7). Increasing epilimnion temperatures and decreasing hypolimnion levels of dissolved oxygen eventually confined the holdovers into restricted areas unfavorable for juvenile salmon (fig. 13). By late September and October, conditions began to improve and the surviving juvenile salmon dispersed throughout the reservoir.

This same sequence of events occurred each year, but with modification. According to Raleigh and Ebel (1967), the amount of reservoir drawdown and the time and duration of the subsequent filling period appeared to be most significant in creating large differences in temperature and oxygen from year to year. In 1965, the large drawdown (28 m.) and prolonged filling (fig. 4) caused late formation of a thermocline, high temperatures, and low oxygen concentrations during late summer. In 1964, drawdown was significant (27 m.) but the filling period was shorter. Water temperatures and oxygen concentrations through the summer were more favorable than in 1965 but less favorable than in 1963, when the drawdown was small (3 m.) and the filling period was early and short.

Estimates of movement of juvenile fall chinook salmon into Brownlee Reservoir (Krcma and Raleigh, 1970) and later escapement (Sims, 1970) verified that the survival of holdover salmon was extremely poor. Fortunately, the conditions that brought about the harshest summer environment (large drawdown and delayed fill) were also the conditions that facilitated rapid passage of fingerlings through the impoundment (Ebel and Koski, 1968; Sims, 1970).

Holdovers of salmon were encountered in the Powder River Arm in October 1962 when 75 chinook salmon were caught. Two of these fish bore fin clips that identified them as progeny of fall chinook salmon from the Snake River that had entered the reservoir in the spring. One fish of this group was also recaptured at the upper end of the main reservoir in the spring of 1963.

In early summer of 1963, fall chinook salmon were captured in gill nets in the lower Powder River Arm. As the environment improved in the fall, many fish moved into the upper arm. From mid-September to mid-December, 561 chinook salmon were captured; of these 444 were tagged and released. The subsequent capture of 28 marked fish in the area of release provided evidence that some fall chinook salmon remained in the upper arm until drawndown in December. On the basis of captures of tagged and untagged fish in the Powder River Arm, a population estimate (made by the technique of Schnabel, 1938) of chinook salmon in the arm ranged from 2,631 to 6,521; the average of 22 estimates was 3,883.

The movement of holdovers from Brownlee Reservoir in 1963 began in January and peaked in February. A total of 5,396 fish were caught in the skimmer net and in scoop traps below the dam. The exodus in 1964 started in November, peaked in January, and was completed by mid-May (Sims, 1970). The total catch of the skimmer net (partially deactivated in February) and the scoop traps was 1,275 fish. This early outmigration appeared to be a displacement because of the approach of a cold water mass through the reservoir (fig. 14).

The recapture of marked holdover fall chinook salmon within the reservoir in 1963 provided information on movements of these fingerlings. Early in the year (before April) most of the fish moved toward the dam, but many moved upstream and a few were recaptured in the area of release. The recapture of fish in all areas of the reservoir and the relatively slow rates of movement indi-

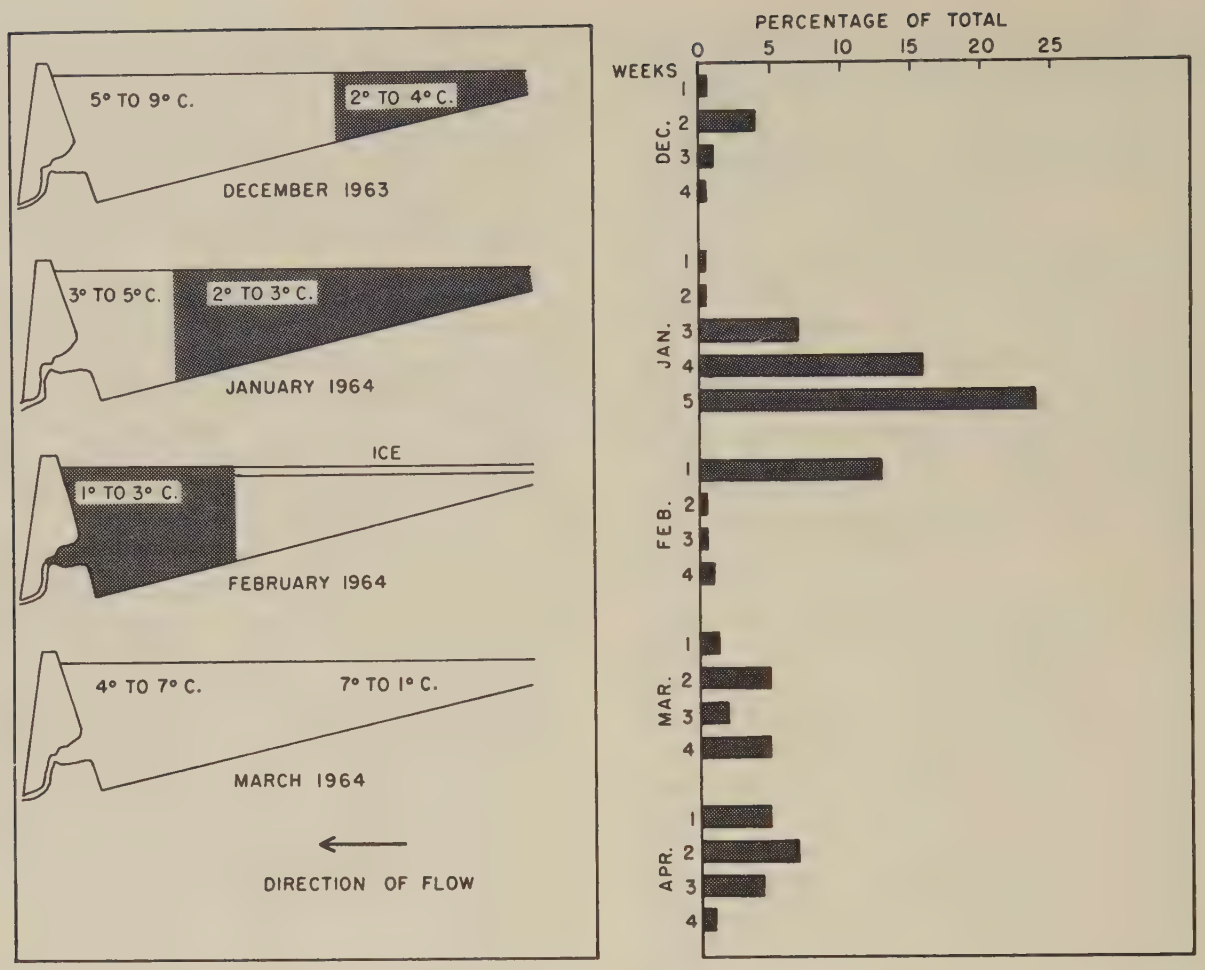

FIGURE 14.—Movement of holdover fall chinook salmon from Brownlee Reservoir in relation to water temperature. (The early outmigration coincided with the approach of a mass of cold water.)

cated that these fish were wandering. As the season progressed, however, the increases in the proportion and rate of movement downreservoir suggest the onset of a directed migration (fig. 15).

The holdover of fingerling salmon in Brownlee Reservoir was evident during each year of study, but the percentage of the total involved, as indicated from reservoir recruitment and escapement estimates (Krcma and Raleigh, 1970; Sims, 1970), fluctuated significantly. The percentage of holdovers seemed to be smallest in 1965, intermediate in 1964, and highest in 1963. The yearly percentage of holdovers varied inversely with reservoir conditions conducive to good passage of fish (figs. 4 and 5).

KOKANEE OF AGE-GROUP I

A few kokanee were caught in the reservoir in 1963 and 1964, and large numbers entered the reservoir in 1965 (table 3). The fish were probably from the Payette River system (Payette Lakes and Cascade and Deadwood Reservoirs). The migration appeared each year in early June, peaked in mid- to late June, and continued into July. Too few fish were present in 1963 or 1964 to determine movement within the reservoir. In 1965, however, it was evident from gill net catches and the recapture of tagged fish that through June the migrants consistently moved downreservoir. By mid-July, when the reservoir was full and the outflow was greatly diminished, fish were moving upreservoir and downreservoir in about equal numbers.

Kokanee were captured near the surface early in the migration, but as the season progressed and the environment deteriorated, the population was concentrated near the dam at depths of 18 to 47 m., as were other salmon species that held over (fig. 13).

TABLE 3.—*Estimated length and numbers of kokanee that entered Brownlee Reservoir, 1963–65 (from Krcma and Raleigh, 1970)*

Year	Fish	Length	
		Mean	Range
	Number	*Mm.*	*Mm.*
1963	500		
1964	5,500	120	104–146
1965	506,800	108	70–155

Kokanee populations that passed through Brownlee Reservoir did not do well. The fish that we observed did not leave their nursery area until late spring. They arrived at Brownlee Reservoir when the impoundment was filling or full, the temperatures were rising, and spillway flow was reduced. If they did not move through the reservoir, the harsh environment in late summer probably caused almost total mortality. Emigration estimates made by Sims (1970) suggested that losses were large in 1964 and 1965. These fish apparently were unable to survive through the summer—a few holdovers of the 1962 migration were captured in 1963, but none were observed in later years.

DISTRIBUTION AND MOVEMENT OF HATCHERY-REARED SALMON

To bolster the dwindling numbers of native salmon and to observe the effect of the reservoir on the passage of other salmon species, we placed hatchery-reared fall chinook and coho salmon juveniles in the Snake River about 120 km. above the reservoir in 1964 and introduced hatchery-reared sockeye and fall-chinook juvenile salmon about 88 km. above the reservoir in 1965 (Krcma and Raleigh, 1970).

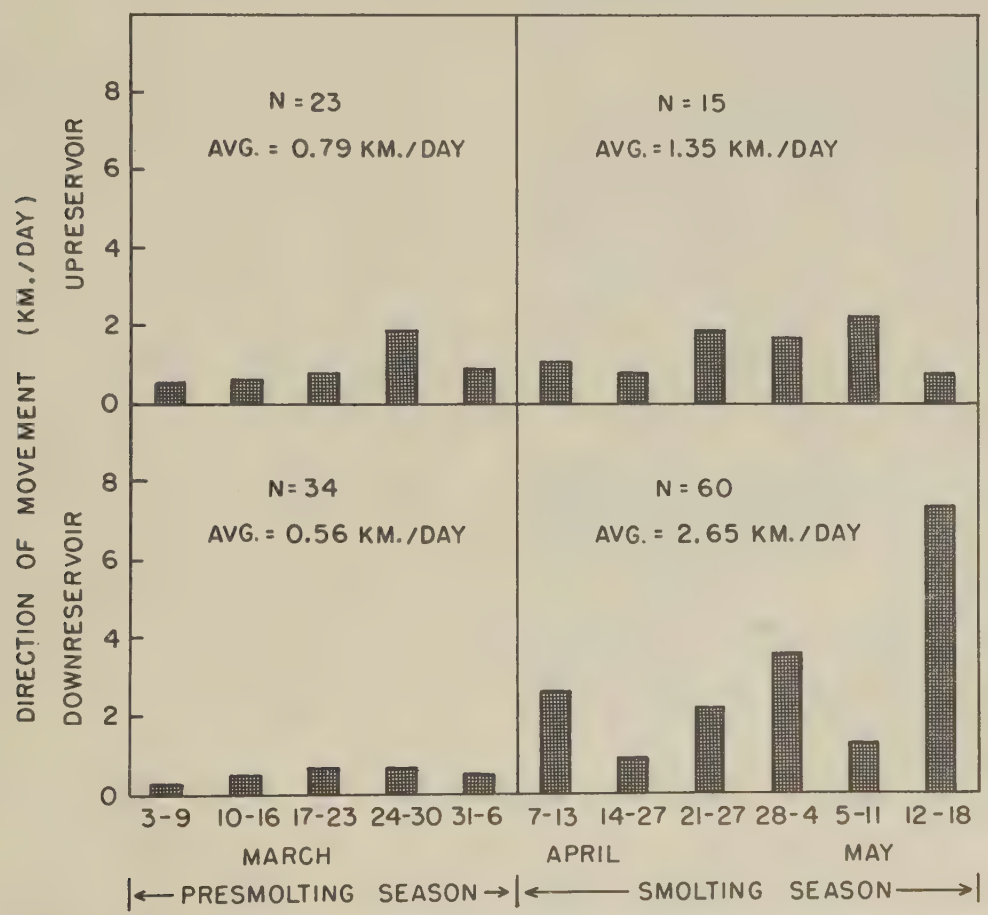

FIGURE 15.—Numbers of tagged juvenile chinook salmon holdovers recovered in Brownlee Reservoir, March 3 to May 18, 1963, showing direction and rate of movement.

FALL CHINOOK SALMON OF AGE-GROUP 0

Hatchery-reared fall chinook salmon were released in the Snake River about 120 km. above Brownlee Reservoir in March 1964 and 1965. Although released over a period of only 10 days, their movement into the reservoir extended over 3 months. Early and late migrants were 46 mm. and 130 mm. long in 1964 and 67 mm. and 135 mm. in 1965.

In 1964 and 1965, tagged hatchery chinook salmon moved primarily toward the dam until mid-May. After mid-May in 1964, some tagged fish were recaptured moving upreservoir; four tagged fish were recaptured in traps in the Snake River about 4 km. upstream from the head of the reservoir (Krcma and Raleigh, 1970). This upstream movement involved fewer fish in 1965. According to Sims (1970), 50 percent of the estimated migration of hatchery-reared chinook salmon into Brownlee Reservoir had left by the end of June 1964 and over 97 percent in 1965.

The movement upstream into the Snake River in 1964 might have been related to temperature, as noted previously for populations of native juvenile chinook salmon.

The ability of these fish to move through the reservoir to the river below Brownlee Dam (50 percent in 1964 and 97 percent in 1965) appeared to vary with volume of flow, direction of current, and length of reservoir. The drawdown lasted 6 weeks longer in 1965 than in 1964 and was accompanied by spillway discharges of large volume and duration and high volumes of inflow from the Snake River (fig. 4). During the 1965 migration this condition produced not only a smaller impoundment (45–50 km. long) but currents of higher velocity that were more consistently toward the dam than in 1964.

The rate of movement of tagged chinook salmon in the reservoir was similar in 1964 and 1965 even though the environments were different. The rate for all chinook salmon that moved toward the outlet averaged 3.0 and 2.9 km./day, respectively (table 4). Fish tagged through the first half of May generally moved faster than those tagged later. Upreservoir movement for nine chinook salmon averaged 0.89 km./day in 1964 and 2.0 km./day in 1965.

Chinook salmon recaptured downriver at Ice Harbor Dam averaged 19.9 km./day in 1964 and 18.8 km./day in 1965 through the reservoir and river.

Fish captured early in the season in midreservoir and along both banks indicated that fall chinook salmon of age-group O were distributed throughout the surface area. Gill net catches showed that juvenile chinook salmon moved both up and down the reservoir during darkness. This observation implies that most directed movement may have occurred during daylight and that fish milled or were carried by currents during darkness.

The distribution of hatchery-reared fall chinook salmon through the summer was similar to that of native fall chinook salmon (fig. 16). In the spring the fish were generally distributed throughout the epilimnion of the reservoir. As the surface temperature increased the fish moved into deeper water and downreservoir. Temperatures above 21° C. at the surface and low oxygen concentrations (less than 3 p.p.m.) at depths where the water was cooler forced the fish to move into restricted areas. The increased catches of fish in gill nets in the upper reservoir in June and July were probably the result of fish returning from a temporary upstream movement into the Snake River.

Some hatchery-reared chinook salmon from the 1964 release remained in Brownlee Reservoir during the winter. Sims (1970) estimated that only about 85 percent of the hatchery-reared fall chinook salmon that entered the reservoir in 1964 migrated out that year. Also 17 fish from this group were captured in the reservoir in February and March 1965.

TABLE 4.—*Summary of direction and rate of movement of tagged age-group O hatchery-reared fall chinook salmon in Brownlee Reservoir, 1964–65*

Year	Direction of movement				Rate of movement					
	Recaptured	Upreservoir	Downreservoir	No movement	Upreservoir	Range	Downreservoir	Range	Brownlee Reservoir to Ice Harbor	Range
	Number	*Number*	*Number*	*Number*	*Km./day*		*Km./day*		*Km./day*	
1964	60	9	37	14	0.89	0.06–1.85	3.0	0.31–9.7	19.9	12.6–33.8
1965	277	14	237	46	2.0	.08–9.76	2.9	.06–8.7	18.8	8.0–42.0

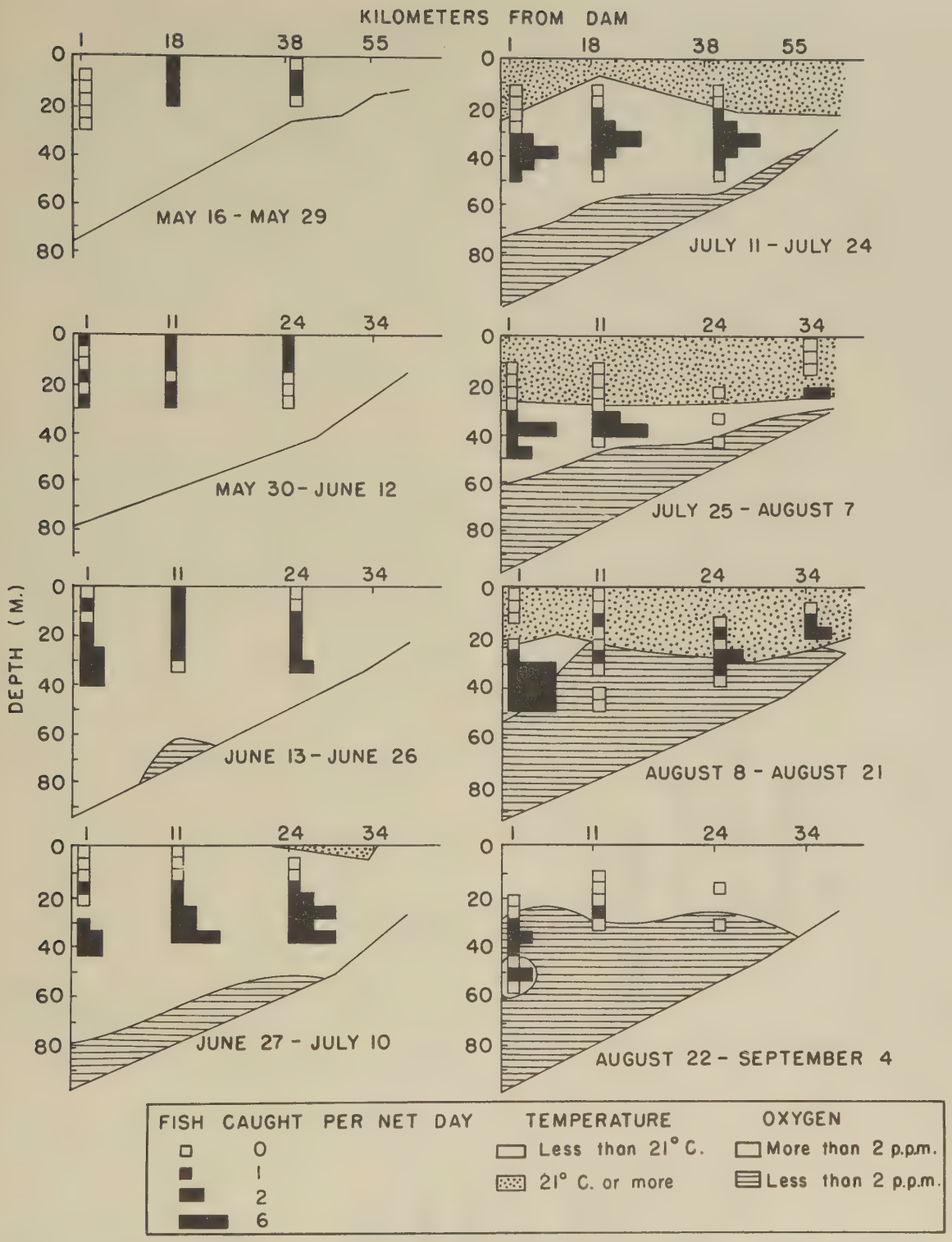

FIGURE 16.—Distribution of hatchery-reared fall chinook salmon in Brownlee Reservoir in relation to critical oxygen and temperature regimes as determined from gill net catches, 1965.

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COHO SALMON OF AGE-GROUP I

Of 375,000 juvenile coho salmon released in the Snake River 120 km. above the reservoir from March 15 to 30, 1964, an estimated 69,000 entered the reservoir (Krcma and Raleigh, 1970). Early in the migration these fish averaged 112 mm. long; by the end they averaged 131 mm.

On the basis of peak catches at the Snake River trapping site above the reservoir and at the dam, passage time through the reservoir was 2 weeks (fig. 17). The reservoir was only 64 km. long at the beginning of the migration as a result of a 13.5-m. drawdown; the distance between the reservoir and the trapping site in the river was about 35 km.

Recapture data from 26 tagged fish indicated that the rate of movement changed during the migration (fig. 18). Before May 20 when the reservoir was drawn down about 13 m. and the outflow volume was large (about 850 c.m.s.), 17 tagged migrants averaged 1.8 km./day. As the outflow was curtailed and the reservoir began to fill, the migration rate of nine tagged fish then dropped to 0.9 km./day. At this time the proportion of fish moving upreservoir also appeared to increase.

In early May most coho salmon were near the surface in the upper reservoir, but by the end of the month most had shifted to the vicinity of the dam at greater depths. As the migration rate slowed in late May and recruitment from the Snake River continued, catches were again good in the upper reservoir. In July the greatest concentration appeared to be in midreservoir at depths of 18 to 31 m. Catches declined through July, and only a few fish were captured thereafter.

SOCKEYE SALMON OF AGE-GROUP I

In 1965, 473,000 yearling sockeye salmon were released in the Snake River, 88 km. above Brownlee Reservoir. Krcma and Raleigh (1970) estimated that 360,000 had entered the reservoir. The salmon were from Babine Lake, British Columbia and reared to yearling stage at the Leavenworth National Hatchery, Wash. The left ventral fin was clipped on all fish. Migrants in March averaged 121 mm.; later migrants averaged 130 mm. by mid-May.

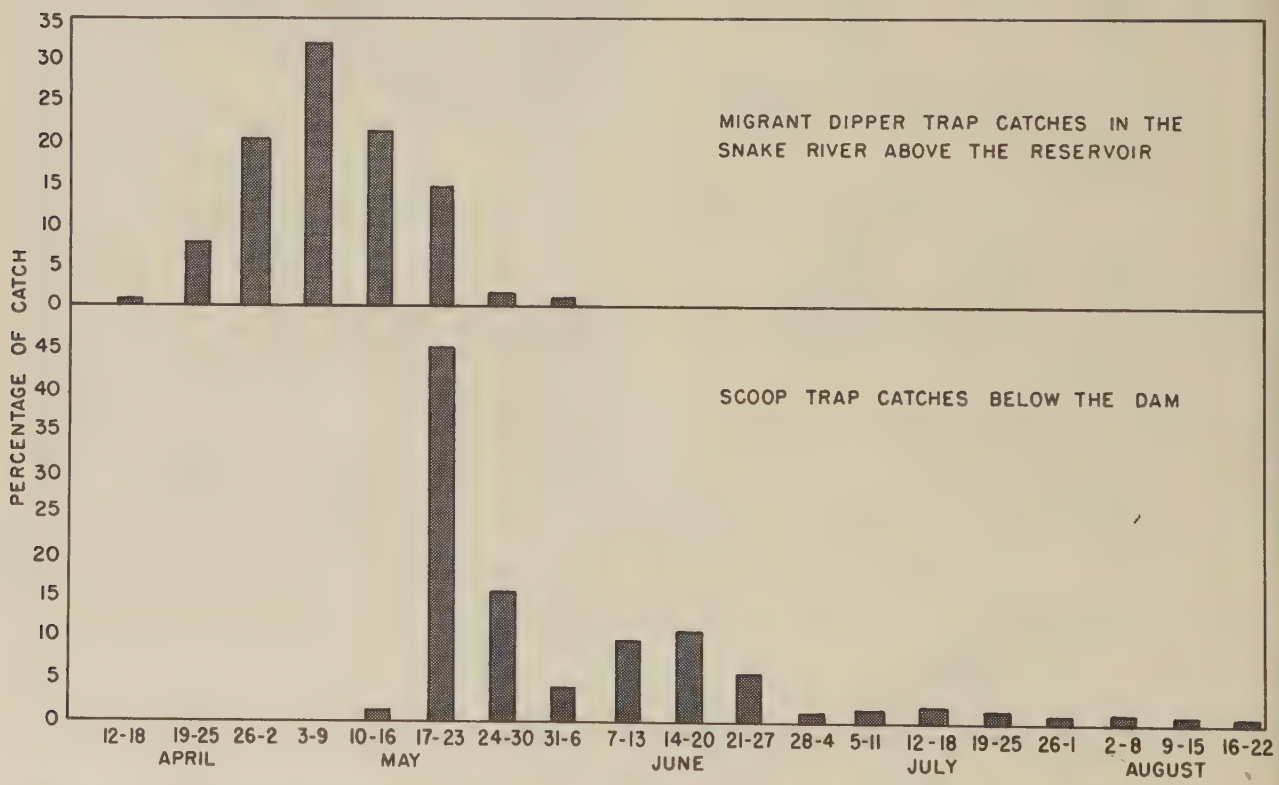

FIGURE 17.—Weekly catches of juvenile hatchery-reared coho salmon above Brownlee Reservoir and below Brownlee Dam, 1964.

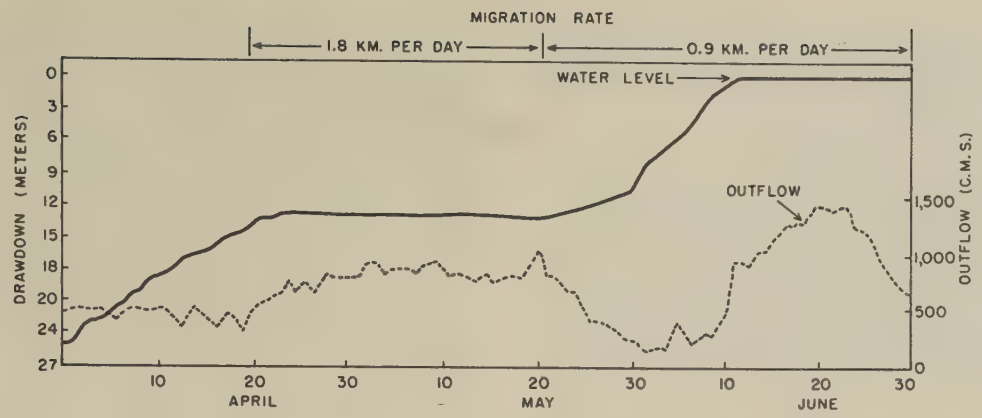

FIGURE 18.—Rate of downstream movement of tagged hatchery-reared coho salmon in relation to water level and outflow in Brownlee Reservoir, April 1 to June 30, 1964.

These fish moved rapidly downstream after release. The first sockeye salmon were captured in the reservoir on March 17—2 days after the initial release. Catches above the reservoir reached a peak during the first week of April and below the reservoir the following week. During the ensuing 2 months, 44 sockeye salmon were recaptured at Ice Harbor Dam and two at Bonneville Dam. The capture of fish in gill nets in the reservoir indicated that the fish moved consistently downreservoir. No sockeye salmon were observed in the Powder River Arm, and no delay within the reservoir was evident.

The average daily rate of movement for 117 tagged sockeye salmon that moved toward the outlet was 5.2 km./day. On the basis of this rate and the length of the reservoir (45–50 km.) in late March and early April, sockeye salmon required an average of about 8 or 9 days to move through the reservoir.

Most sockeye salmon were captured within 4.5 m. of the surface, some were between 4.5 and 13.5 m., and a few were taken as deep as 22.5 m. (table 5). Data on catch per unit of effort at three gill net stations indicated that the vertical distribution was similar throughout the reservoir.

Sockeye salmon were captured near shore and offshore in the upper reservoir. In the lower reservoir they were captured almost exclusively offshore. The recovery of tagged sockeye salmon indicated that fish tagged near the shore eventually moved to the open water, whereas those tagged offshore remained offshore.

During the migration period from March through mid-May 1965, the environment was favorable for fish passage. Dissolved oxygen concentrations were 6 to 11 p.p.m. until early May, and temperatures ranged from about 5° C. in late March to 15° C. in late April. The reservoir level was 24 to 30 m. below full pool through mid-May, and its length was reduced to about 45 km. Spill discharge at Brownlee Dam was continuous, ranging from a weekly average of 424.5 to 1,440.3 c.m.s. Current monitors, operated by personnel studying the limnology of the reservoir, revealed that surface currents were oriented toward the outlet. Ac-

TABLE 5.—*Depth distribution of sockeye salmon yearlings as indicated by the catch per gill net day at different depths in Brownlee Reservoir, March 17 to April 26, 1965* [1]

Depth	Mile 1			Mile 12			Mile 24		
	Sets	Sockeye	Catch per unit effort	Sets	Sockeye	Catch per unit effort	Sets	Sockeye	Catch per unit effort
M	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
<1.4	7	247	35.3	4	312	78.0	6	205	34.2
1.5–4.1	2	3	1.5	3	8	2.7	3	10	3.3
4.2–13.7	5	4	0.8	4	3	0.8	6	10	1.7
13.8–18.3	2	0	0.0	3	3	1.0	4	3	0.8
18.4–22.9	5	3	0.6	1	4	4.0	4	3	0.8
23.0–27.5	2	0	0.0						

[1] Mesh sizes used were 1.9, 2.5, 3.1, and 3.8 cm. stretched mesh.

cording to Sims (1970), nearly 100 percent of the sockeye salmon migration had passed through Brownlee Reservoir.

SUMMARY

The distribution and movement of juvenile salmon that migrate through Brownlee Reservoir, a large impoundment on the Snake River, was studied from 1962 to 1965. The study included native spring and fall chinook salmon and kokanee and hatchery-reared fall chinook, coho, and sockeye salmon.

Each native salmon population had a characteristic age, size, and time of entry into the reservoir. Most spring chinook salmon from Eagle Creek entered the reservoir in the late fall as age-group O, 53 to 125 mm. long. These fish overwintered in the reservoir, primarily in the Powder River Arm. They resumed their seaward migration in the spring just before the peak of a second outmigration from Eagle Creek in March and April of age-group I fish, 65 to 138 mm. long. The migration of juvenile spring chinook salmon from the Weiser River entered the reservoir in peak numbers in late April or early May; it consisted of age-group I fish, 106 to 176 mm. long. This movement was closely followed by that of age-group O fall chinook salmon from the Snake River, 33 to 105 mm. long, which entered the reservoir in peak numbers in mid-May. Kokanee migrants entered the reservoir latest in the season; age-group I fish, 70 to 155 mm. long, arrived in mid-June.

Hatchery-reared groups of salmon migrated into the reservoir as follows: fall chinook salmon of age-group O (46–135 mm.) in mid-May of 1964 and 1965; coho salmon of age-group I (71–166 mm.) in mid-May 1964; and sockeye salmon of age-group I (86–175 mm.) in early April 1965.

Migrants from all populations were near the surface as they entered. As the season progressed and the juvenile fish moved downreservoir, they tended to move into deeper water.

Migration peaks from the reservoir varied from year to year, depending on reservoir conditions, but were sequential by stock. Fish (mainly fall chinook salmon) that remained in the reservoir from the previous year's migration left the reservoir early (late January or February) at the approach of a cold water mass that moved through the reservoir. This migration was followed in late February and early March by fish (mainly fall chinook salmon) that had overwintered in the Powder River Arm. Spring migrants from Eagle Creek and Weiser River arrived at the dam in large numbers in April and May. Fall chinook salmon from the Snake River arrived in late May to early July and kokanee, in July or August. Hatchery-reared fall chinook salmon left in May 1964 and in April 1965, coho salmon in late May 1964, and sockeye salmon in April 1965.

Juvenile fish that did not leave the reservoir by late June or July were confined to restricted areas of the reservoir by high epilimnion temperatures and low concentrations of dissolved oxygen, which extended into the epilimnion from the hypolimnion. When this process began, juvenile salmon in the upper end of the reservoir usually reentered the slightly cooler waters of the Snake River. They returned to the reservoir when temperatures in the river began to approach 20° C. The survival of holdover salmon through the summer and early fall was extremely poor.

The differences in success of passage through the reservoir were more closely related to the physical conditions of the reservoir than to behavioral differences between species of salmon stocks. Success of passage for all populations was poorest in 1963 when the reservoir was nearly full throughout the migration. Under this condition, the reservoir was 92 km. long and surface currents were either weak or nonexistent and often moved upreservoir. Passage through the reservoir was intermediate in 1962 and 1964 when drawdown was 6 to 14 m. through May and the reservoir averaged 70 km. long. The most successful passage was in 1965 when the drawdown was large (26–28 m. through May), the reservoir was relatively small (45–50 km. long), and currents were consistently oriented downstream. Loss of orientation and upreservoir movement of the juvenile salmon were correlated with conditions in the reservoir most prevalent in 1963 and least prevalent in 1965.

Early entrance into the reservoir appeared to improve the chances of successful passage. In general, early fish encountered the best combination of reservoir length, current conditions, and environment. Late migrants, such as the kokanee, entered a rapidly deteriorating environment, and their success of passage was extremely poor.

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EMIGRATION OF JUVENILE SALMON AND TROUT FROM BROWNLEE RESERVOIR, 1963–65

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ABSTRACT

Floating scoop traps below Brownlee Dam captured samples of marked and unmarked salmon and trout that had left the impoundment from July 1963 through August 1965; estimates of emigration were based on these samples.

Success of passage varied among years and populations and was affected by the environment in the reservoir during outmigration. Downstream migrants that entered the reservoir early in the season were more successful than those that entered later. Emigration was also more successful when the reservoir level was low.

Brownlee Reservoir was chosen for an extensive research program by BCF (Bureau of Commercial Fisheries) to determine how a large impoundment affects the passage of salmon and trout. The research, begun in the spring of 1962, consisted of five studies: (1) limnology of the reservoir system (Ebel and Koski, 1968); (2) upstream migration of adult chinook salmon (*Oncorhynchus tshawytscha*) through the reservoir (Trefethen and Sutherland, 1968); (3) migration of juvenile salmon and trout into the reservoir (Krcma and Raleigh, 1970); (4) distribution and movement of juvenile salmon in the reservoir (Durkin, Park, and Raleigh, 1970); and (5) migration of juvenile salmon and trout from the reservoir (the present report).

Brownlee Reservoir, on the middle Snake River, lies at the southern end of Hells Canyon along the border between northeast Oregon and western Idaho. The reservoir is about 92 km. long and averages slightly less than 800 m. wide. Brownlee Dam (constructed by the Idaho Power Company) is a high-head structure, the primary function of which is hydroelectric power production. It is 396 m. wide on the top, has a single spillway and four Francis turbines with vertical shafts, and creates 83 m. of head at full pool. The dam discharges directly into Oxbow Reservoir, formed by Oxbow Dam about 19 km. downstream.

In an attempt to provide facilities for the passage of juvenile salmon and trout past Brownlee Dam, the Idaho Power Company installed a fingerling-collection system in 1959 in the forebay of the reservoir about 3 km. downstream from the dam (Soule, Heikes, Mitchell, and Schaufelberger, 1959). The system, consisting of a shore-to-shore barrier net and surface collection traps, proved only partly successful.[1] Many fingerlings passed under or through the barrier net and left the reservoir via the turbines or spillway. Idaho Power Company removed the system in February 1964, after which all fish that left the reservoir passed through the turbines or spillway.

Native populations of anadromous salmon and trout affected by Brownlee Reservoir include fall- and spring-run chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Salmo gairdneri*). Before the construction of Brownlee Dam in 1958, the largest population was fall-run chinook salmon, which spawned in the Snake River upstream from what is now the upper end of Brownlee Reservoir. The Fish Commission of Oregon estimated annual fall chinook salmon spawning runs of as many as 20,000 fish in the late 1950's. By 1963 this population was greatly reduced. Before 1963, spring-run chinook salmon spawned in the Weiser River (a tributary of the Snake River above the head of the reservoir) and in Eagle Creek (a tributary of the Powder River, which enters near the lower end of the reservoir). Steelhead trout were native to Weiser River and Eagle Creek as well as several

[1] Graben, James E. 1964. Evaluation of fish facilities, Brownlee and Oxbow Dams, Snake River. Idaho Department of Fish and Game, Boise, Idaho, 60 pp. (Processed.)

Published April 1970.

streams above Brownlee Dam. Several impoundments in the Snake River system above Brownlee Reservoir support populations of kokanee (*O. nerka*); these fish periodically move into the Brownlee area.

After the decline of the native runs, hatchery-reared chinook, coho (*O. kisutch*), and sockeye salmon were released in the Snake River above Brownlee Reservoir by the BCF in 1964 and 1965 to provide additional fish for study.

The study on the passage of juvenile salmon and trout from Brownlee Reservoir began in July 1963 and continued through the summer of 1965. I report here the number and size of emigrants and the time of emigration.

TECHNIQUES OF SAMPLING AND ANALYSIS

The sampling area (fig. 1) was immediately below Brownlee Dam. About 180 m. below the powerhouse the turbine tailrace channel enters the original river channel, which carries the intermittent discharges from the spillway of the dam. The Interstate Bridge crosses Oxbow Reservoir about 600 m. downstream from the dam. At that point, the reservoir is about 160 m. wide and 3.5 m. deep at midchannel when Oxbow Reservoir is at full pool.

The primary sampling site was in the turbine tailrace, about 150 m. below the powerhouse. The turbine tailrace is about 76 m. wide; the water is about 4 m. to 7 m. deep, depending on the level of Oxbow Reservoir and the discharge from Brownlee Dam. Because fish that passed over the spillway could not be sampled at the tailrace site, an additional sampling site was established downstream at the Interstate Bridge for use during periods of spillway operation.

The analyses of the data involved an evaluation of (1) equipment, (2) procedures, (3) tests of sampling efficiency, and (4) methods of computing emigration.

FIGURE 1.—Turbine tailrace (foreground) at Brownlee Dam with scoop traps in position below right bank. Spillway (not in operation in this photo) enters original river channel on extreme left.

FIGURE 2.—Scoop traps in operation in the turbine tailrace.

EQUIPMENT

Three scoop traps (fig. 2) were used to collect juvenile migrants.[2] Each trap was 3.0 m. wide by 3.2 m. long and fished at a depth of 1.2 m. A pontoon-type barge, 5.5 m. by 7.5 m., supported the individual traps and winch equipment. In the turbine tailrace, the traps were close to the right (Idaho) bank. At the Interstate Bridge, one trap was in the center of the channel and the other two were about 30 m. from the right and left banks.

PROCEDURES

The traps were emptied of fish and cleared of debris at 8 a.m. and 4 p.m. Additional checks were made at noon and at midnight during peak outmigration and at any time that excessive debris accumulated. During special studies, the traps were emptied of fish and debris at intervals of 1, 4, and 6 hours.

All salmon and trout were identified, examined for marks or tags, and measured for fork and standard length. All live salmon and trout were anesthetized before examination and then were released unless needed for special studies. Scale samples were taken from dead and injured fish when possible.

TESTS OF TRAP EFFICIENCIES

Fish marked by partial fin clip, tattoo, or thermal brand were used to evaluate the efficiency of the scoop traps at both sampling sites. Hatchery-reared juveniles were used for marking in all years, except in 1964 when a few tests were made with native age-group I spring and fall chinook salmon from scoop trap catches. Hatchery-reared age-group 0 chinook salmon were used in 1964 and 1965, age-group I coho salmon in 1964, and sockeye salmon in 1965.

Tests at the Interstate Bridge required that test fish be released into the spillway and into the turbine penstocks; tests at the turbine tailrace site required releases only into the penstocks. Pen-

[2] Bell, Robert. 1959. Time, size, and estimated numbers of seaward migrations of chinook salmon and steelhead trout in the Brownlee-Oxbow section of the middle Snake River. Idaho Department of Fish and Game, Boise, Idaho, 34 pp. (Processed.)

stock releases were made by pumping the test fish down the penstock air vent through a 76-mm. hose.

In 1964, about 1,570 hatchery-reared juvenile chinook salmon and an equal number of juvenile coho salmon were released into the spillway and turbine penstocks to determine efficiency of the traps at the Interstate Bridge (table 1). Fifteen chinook and 15 coho salmon were recaptured, (0.95-percent return for each species). Trapping efficiency for chinook salmon was slightly higher in 1965 when 1,171 hatchery-reared test fish were released and 15 fish (1.28 percent) were recaptured (table 2). Recovery efficiency of the traps for hatchery-reared sockeye salmon fingerlings released in 1965 was significantly higher than for chinook salmon; 2,670 test sockeye salmon were released and 71 (2.66 percent) were recaptured at the bridge site (table 3).

The scoop traps were more efficient in the turbine tailrace than at the Interstate Bridge. In 1964–65, 8,471 test fish (hatchery-reared juvenile chinook, coho, and sockeye salmon) were released into the various turbine penstocks for recovery in the turbine tailrace. Differences in average recovery between years and among species were so slight that the data were combined. Recoveries for daylight releases (8:00 a.m. to 4:00 p.m.) were 0.5 to 7.5 percent and averaged 4.1 percent (table 4). Recaptures of fish from night releases (4:00 p.m. through 8:00 a.m.) were 4.5 to 29.7 percent and averaged 11.3 percent (table 5).

TABLE 1.—*Numbers of marked juvenile chinook and coho salmon recovered in scoop traps at the Interstate Bridge after release in the spillway (S) or turbines (T) of Brownlee Dam, April 24 to June 30, 1964*

Date (1964)	Fish released	Release site	Average spill	Fish recovered	
	Number		(*M.³/sec.*)	*Number*	*Percent*
April:					
24	101	S	177	1	0.99
25	100	S	185	1	1.00
26	103	S	279	1	.97
27	95	S	405	0	.00
28	100	S	458	0	.00
29	100	S	452	1	1.00
May:					
7	106	S	548	4	3.77
7	89	T	548	4	4.49
8	100	S	642	0	.00
8	100	T	642	1	1.00
15	100	T	510	0	.00
16	100	T	510	2	2.00
20	102	S	579	1	.98
20	100	T	579	0	.00
21	116	T	551	2	1.72
27	106	T	0	1	.94
June:					
11	79	S	332	1	1.27
14	179	S	708	1	.56
15	189	S	737	2	1.06
16	200	S	795	2	1.00
16	200	T	795	1	.50
17	100	T	978	0	.00
18	100	T	1,100	1	1.00
19	100	T	1,136	1	1.00
23	100	S	1,189	0	.00
24	100	S	1,137	1	1.00
25	100	S	961	1	1.00
30	100	S	170	0	.00
Total	3,165			30	.95

TABLE 2.—*Numbers of marked juvenile chinook salmon recovered in scoop traps at the Interstate Bridge after release in the spillway (S) or turbines (T) of Brownlee Dam, April 9 to May 20, 1965*

Date (1965)	Fish released	Release site	Average spill	Fish recovered	
	Number		(*M.³/sec.*)	*Number*	*Percent*
April:					
9	160	S	409	1	0.6
13	102	T	566	2	2.0
13	121	S	566	0	.0
15	107	S	512	2	1.9
21	122	T	1,338	1	.8
25	154	T	1,557	2	1.3
May:					
14	101	S	958	1	1.0
14	106	T	958	2	1.9
20	101	S	622	3	3.0
20	97	T	622	1	1.0
Total	1,171			15	1.28

METHODS OF COMPUTING EMIGRATION

Estimates of emigration were based on live and dead fish caught in the scoop traps. Identity of the various populations was determined from fish that had been marked in the tributary drainages and subsequently recovered in the scoop traps. Length-frequency data and scale samples were also used to determine the origin of different populations of fish emigrating at various times of the year.

Estimates of emigration during periods of sampling at the Interstate Bridge were computed with the general formula (Chapman, 1948):

$$N_1=\frac{C(M+1)}{(R+1)} \qquad (1)$$

where

N=population estimate
C=sample size
M=number of marks
R=marked recaptures in C

To compensate for the variation in efficiency of traps in the turbine tailrace, I computed emigration during periods of sampling at that site with an alternate method:

$$N_2=\frac{\text{trap catch}}{\text{percentage of efficiency}} \qquad (2)$$

Upper and lower limits were computed for estimates of emigration at both sampling sites. For estimates based on sampling at the Interstate

TABLE 3.—*Numbers of marked juvenile sockeye salmon recovered in scoop traps at the Interstate Bridge after release in the spillway (S) or turbines (T) of Brownlee Dam, March 31 to May 15, 1965*

Date (1965)	Fish released	Release site	Average spill	Fish recovered	
	Number		*(M.³/sec.)*	*Number*	*Percent*
March:					
31	241	T	487	6	2.5
April:					
1	95	S	459	2	2.1
2	109	T	425	2	1.8
5	177	S	448	4	2.3
5	275	T	448	8	2.9
6	140	S	519	2	1.4
7	211	T	338	4	1.9
8	238	S	357	5	2.1
9	102	T	409	5	4.9
10	218	S	510	4	1.8
10	103	T	510	3	2.9
11	124	S	511	6	4.8
12	180	S	499	2	1.1
14	110	T	448	4	3.6
15	140	S	511	5	3.6
May:					
15	207	S	511	9	4.3
Total	2,670			71	2.66

TABLE 4.—*Numbers of marked juvenile salmon (chinook, coho, and sockeye) recovered in scoop traps in the Brownlee Dam tailrace between 8 a.m. and 4 p.m., 1964–65*

Date	Total fish released	Number released at turbine number				Turbine discharge	Fish recovered	
		1	2	3	4			
	Number	*Number of fish*				*(M.³/sec.)*	*Number*	*Percent*
1964:								
July 3	200	100			100	618	5	2.5
July 3	200	100			100	612	7	3.5
July 4	200	100			100	439	14	7.0
July 4	200	100			100	448	7	3.5
July 5	200	100			100	379	6	3.0
July 5	200	100			100	399	1	.5
July 5	200	100			100	375	3	1.5
July 7	200		100	100		387	15	7.5
July 7	200		100	100		443	10	5.0
July 7	200		100	100		417	10	5.0
July 8	200		100	100		536	9	4.5
1965:								
June 5	350	96	99	76	79	472	13	3.7
June 5	371	99	100	79	93	472	17	4.6
June 6	392	106	99	87	100	409	22	5.6
June 7	384	95	92	105	92	547	12	3.1
Total	3,697	1,096	790	747	1,064		151	4.11

Bridge, these limits represent the 95-percent confidence limits as computed by Chapman's formula:

$$\overline{m},\ \underline{m}=\mathrm{R}+\frac{1.96^2}{2}\pm 1.96\sqrt{\mathrm{R}+\frac{1.96^2}{4}} \qquad (3)$$

where

$\overline{m}$ and $\underline{m}$ are the upper and lower values of R, respectively.

Upper and lower estimates at the turbine tailrace site were based on the 95-percent confidence interval of the means of the frequency distributions in the respective day-night tests of efficiency (Wilkes, 1948). These values were computed according to the formula:

$$u=\overline{X}\pm t_a\frac{s}{n}$$

where

u=population mean
$\overline{X}$=sample mean
t_a=confidence coefficient
s=standard deviation
n=number of tests

TABLE 5.—*Numbers of marked juvenile salmon (chinook, coho, and sockeye) recovered in scoop traps in the Brownlee Dam tailrace between 4 p.m. and 8 a.m., 1964–65*

Date	Total fish released	Number released at turbine number				Turbine discharge	Fish recovered	
		1	2	3	4			
	Number	*Number of fish*				*(M.³/sec.)*	*Number*	*Percent*
1964:								
July 3	200	100			100	577	10	5.0
July 4	200	100			100	378	9	4.5
July 5	200	100			100	349	13	6.5
July 7	100			100		364	7	7.0
July 11	300	100	100	100		268	25	8.3
July 11	300	100		100	100	263	26	8.7
July 12	200	100		100		228	34	17.0
July 12	200		100	100		294	34	17.0
July 14	200	100		100		301	15	7.5
July 15	100	100				84	6	6.0
July 15	300	100		100	100	343	27	9.0
July 15	200			100	100	214	28	14.0
July 16	300		100	100	100	339	89	29.7
July 17	200	100		100		303	12	6.0
July 18	300		100	100	100	408	34	11.3
1965:								
June 5	409	110	100	99	100	553	36	8.8
June 5	364	61	99	99	105	168	54	14.8
June 6	381	94	96	101	90	159	52	13.6
June 7	320	98	98	59	65	358	30	9.4
Total	4,774	1,363	793	1,458	1,160		541	11.33

Estimates of annual emigration were based on scoop trap catches from May 1963 through August 1965 (table 6). No tests of efficiency of scoop traps were made in 1963; therefore, estimates of emigration for that year were based on efficiency tests in 1964. In the estimates of emigration, catches by the Idaho Power Company barrier net in 1964 were also included. Estimates of immigration used to compare with estimates of emigration were from Krcma and Raleigh (1970).

ESTIMATES OF EMIGRATION

EMIGRATION OF NATIVE SALMON

The migration of juvenile salmon and trout from Brownlee Reservoir included three native and three hatchery-reared salmon populations and a trout population of unknown origin. Estimates of emigration were made for each population.

Native juvenile salmon migrating through Brownlee Reservoir included fall chinook salmon and kokanee from the Snake River and spring chinook salmon from Eagle Creek and the Weiser River.

TABLE 6.—*Catches of juvenile salmon and rainbow-steelhead trout by scoop traps below Brownlee Dam, May 1, 1963 to August 31, 1965* [1]

Date (year and month)	Chinook salmon	Coho salmon	Sockeye salmon	Kokanee salmon	Rainbow-steelhead trout
1963:	*Number*	*Number*	*Number*	*Number*	*Number*
May	2				
June	194				
July	62				
August	82				13
September	16				1
October	8				1
November	49				1
December	101				
1964:					
January	247				14
February	273				11
March	370				28
April	885				114
May	505	256			79
June	621	262		2	76
July	56	124		11	51
August	114	84		90	32
September	25	3		2	3
October	7			1	4
November	8				4
December	2				3
1965:					
January	2				2
February	2				
March	14		2,214		9
April	2,198		8,162		338
May	900		8		392
June	1,802			80	142
July	111			193	34
August	208			3,077	128
Total	8,864	729	10,384	3,456	1,480

[1] Catches by scoop trap reported by Graben, 1964 (see text footnote 1).

Fall Chinook Salmon

An estimated 54,800 native fall chinook salmon from the Snake River left the reservoir in 1963 as age-group 0 and in 1964 as age-group I (table 7). Of these fish, 2,700 were captured by the Idaho Power Company barrier net in the forebay of the reservoir and transported below Oxbow Dam and released. Total emigration of the 1963 year class was about 15 percent of established immigration to the reservoir (table 7).

Age-group-0 fish from the 1963 year class first appeared in the scoop traps below the dam in May 1963 (fig. 3); peak migration was in June. Except for one period in 1963 (late September to early October), some fish moved past the dam throughout the summer and fall. About 75 percent of age-group I fish in 1964 (1963 year class) left the reservoir in late January; a second peak appeared in early April.

Spring Chinook Salmon

Emigration of juvenile spring chinook salmon of the 1963 year class was 5,900 fish or about 16 percent of the estimated immigration from the Weiser River and Eagle Creek to the reservoir (table 8). A small number from Eagle Creek began

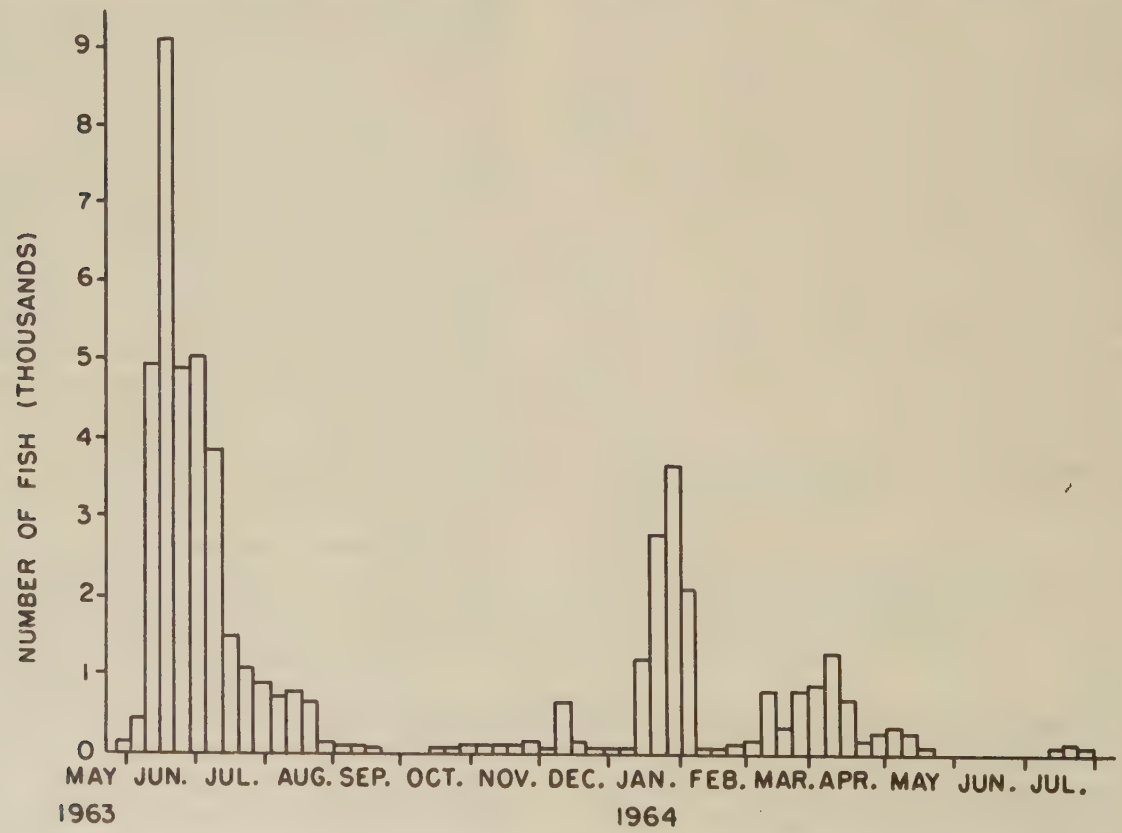

FIGURE 3.—Estimated emigration from Brownlee Reservoir of juvenile native fall chinook salmon (1963 year class), from the Snake River, May 1963 to August 1964.

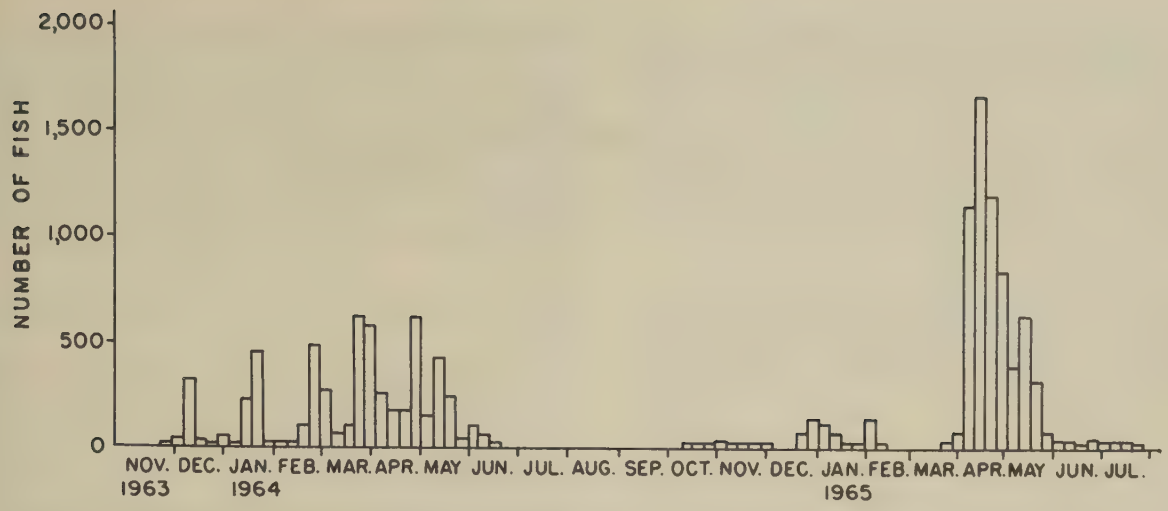

FIGURE 4.—Estimated emigration from Brownlee Reservoir of juvenile native spring chinook salmon from Eagle Creek and Weiser River, November 1963 to July 1965.

TABLE 7.—*Estimated immigration of juvenile native fall chinook salmon into Brownlee Reservoir from the Snake River and estimated emigration from the Reservoir, May 1, 1963 to August 1964 (all fish of 1963 year class)*

Estimated immigration	Years of emigration	Estimated emigration		Range of estimated emigration	
				Low	High
Number		*Number*	*Percent*	*Number*	*Number*
374,000	1963–64	[1] 54,800	15	39,600	72,500

[1] Includes 2,700 fish captured at the Idaho Power Company barrier net.

to leave the reservoir as age-group 0 fish in November 1963, and the emigration continued through June 1964 (fig. 4). Distinction between fish from the Weiser River and those from Eagle Creek was not always possible, but knowledge of the age of fish at the time of downstream migration to the reservoir provided a basis for their identification at certain times of the year. Krcma and Raleigh (1970) have shown that fish from the Weiser River do not enter the reservoir until spring 1 year after hatching, whereas fish from Eagle Creek enter at age 0 in the fall and again as age-group I in the spring. Spring chinook salmon that left the reservoir in the fall, winter, and early spring, therefore, were probably from Eagle Creek; fish leaving later in the spring and in early summer could be from either the Weiser River or Eagle Creek.

The emigration of the 1964 year class of spring chinook salmon was estimated at 14,000 fish, 51 percent of estimated immigration. Most of these fish were from Eagle Creek. Additional catches of juvenile migrants from Eagle Creek were made in the stream, transported downstream below Oxbow Dam, and released (Krcma and Raleigh, 1970). Juvenile spring chinook salmon that entered the reservoir in late March and early April 1964 migrated rapidly through the impoundment. Peak emigration was in mid-April, and the migration ended in late July (fig. 4).

Kokanee

The origin of, or reasons for, some migrations of juvenile kokanee into Brownlee Reservoir are not completely understood, but most fish observed during the present study were probably from the Payette River system (Payette Lakes and Cascade and Deadwood Reservoirs). Kokanee periodically migrate however, and rather large numbers of fingerlings entered Brownlee Reservoir in 1964

TABLE 8.—*Estimated immigration of juvenile native spring chinook salmon into Brownlee Reservoir from Eagle Creek and the Weiser River and estimated emigration from the Reservoir, November 1, 1963 to August 1965*

Year class	Estimated immigration			Years of emigration	Estimated emigration		Range of estimated emigration	
	Weiser River	Eagle Creek	Total				Low	High
	Number	*Number*	*Number*		*Number*	*Percent*	*Number*	*Number*
1963	15,000	22,300	37,300	1963–64	5,900	16	4,700	8,500
1964	6,800	7,200	14,000	1964–65	7,200	51	4,500	11,300

and 1965. In 1964, 2,100 kokanee fingerlings (1963 year class) were estimated to have left the reservoir, representing about 38 percent of the estimated recruitment to the reservoir (table 9). The outmigration started during the latter part of June 1964, reached a peak in early August, and ended by the first week in September.

TABLE 9.—*Estimated immigration of juvenile kokanee into Brownlee Reservoir from the Snake River system and estimated emigration from the Reservoir, May 1964 and 1965*

Year class	Estimated immigration	Year of emigration	Estimated emigration		Range of estimated emigration	
					Low	High
	Number		*Number*	*Percent*	*Number*	*Number*
1963	5,500	1964	2,100	38	1,700	2,900
1964	506,800	1965	52,100	10	4,200	73,200

An estimated half million age-group I kokanee entered Brownlee Reservoir in 1965, but only 10 percent (52,100 fish) are estimated to have left the reservoir. According to Durkin et al. (1970), the poor success of the migration of kokanee can be attributed to the high reservoir level and its attendant lack of downstream-orienting currents. These fish did not enter the reservoir until June and did not begin to leave until late June. The outmigration was greatest in late August and was completed by early September (fig. 5). Fish remaining in the reservoir in late July, August, and September were subjected to high temperatures in the epilimnion (above 21° C.) and oxygen-deficient water in the hypolimnion. These factors forced fish into unfavorable habitats where survival was poor (Durkin et al., 1970).

EMIGRATION OF JUVENILE HATCHERY-REARED SALMON

About 250,000 age-group 0 juvenile fall chinook salmon and 375,000 age I juvenile coho salmon were released in the Snake River above Brownlee Reservoir in late winter and early spring of 1964. Additional releases of 592,000 age-group 0 fall chinook salmon and 473,000 age-group I juvenile sockeye salmon were made in the spring of 1965. Chinook and coho salmon fingerlings were from hatcheries on the lower Columbia River; sockeye salmon fingerlings were from the Leavenworth National Fish Hatchery, where they had been reared from eggs obtained from Babine Lake in British Columbia.

Fall Chinook Salmon

About 85 percent (94,500) of the estimated 111,500 hatchery-reared juvenile fall chinook salmon that entered the reservoir in 1964 passed

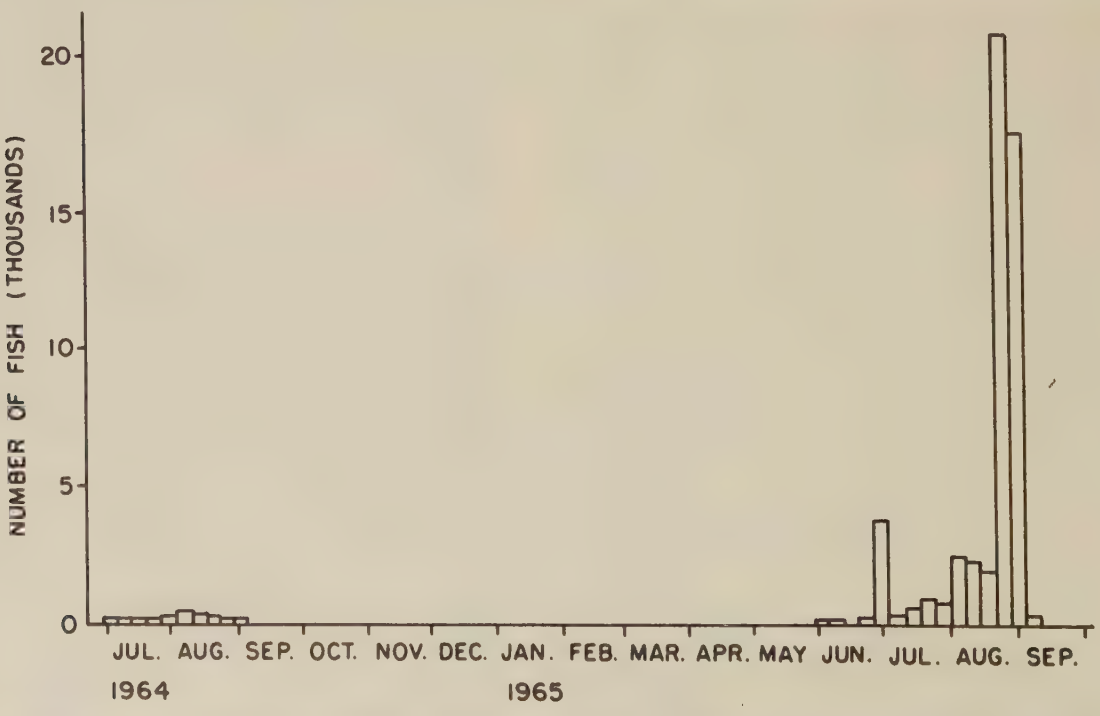

FIGURE 5.—Estimated emigration from Brownlee Reservoir of juvenile native kokanee from the Snake River system, 1964–65.

Brownlee Dam in 1964 (table 10). These fish first appeared at the traps below the dam in early April (9 days after release in the Snake River above the reservoir) and their numbers peaked in the second week of May. Small numbers of fish moved out of the reservoir through the summer until the emigration of the 1964 year class was completed on September 1 (fig. 6).

An estimated 275,200 hatchery-reared fall chinook salmon (1965 year class) left the impoundment in 1965—more than were estimated to have entered the reservoir. The discrepancy between the two estimates is probably due to different sampling methods. Nevertheless, such a comparison is useful when one recognizes that the low range emigration estimate (175,000 fish) is within the 95-percent statistical confidence range of the immigration estimate. Fish of the 1965 year class were first taken in the scoop traps below the dam in late March (fig. 6), 12 days after release in the Snake River above the reservoir. Peak migration was in mid-April, and a few fish were still leaving the reservoir when the experiment terminated at the end of August.

Coho Salmon

Emigration of juvenile hatchery-reared coho salmon (1963 year class) in 1964 was estimated at 51,600 fish or about 75 percent of immigration to the reservoir (table 11). The emigration of coho salmon began on May 16, 1964, about 6 weeks after their release in the Snake River above the reservoir. The run reached a peak 1 week later and continued until the end of August (fig. 7).

TABLE 10.—*Estimated immigration of juvenile hatchery-reared fall chinook salmon into Brownlee Reservoir from the Snake River and estimated emigration from the Reservoir, 1964–65*

Year class	Estimated immigration	Year of emigration	Estimated emigration		Range of estimated emigration	
					Low	High
	Number		*Number*	*Percent*	*Number*	*Number*
1964	111,500	1964	94,500	85	68,600	133,400
1965	162,800	1965	[1] 275,000	[1] >100+	175,000	432,000

[1] Discrepancy between estimates of immigration and emigration probably due to differences in sampling techniques in the Snake River and below Brownlee Reservoir.

Sockeye Salmon

Juvenile hatchery-reared sockeye salmon (1964 year class) released in 1965 had little difficulty in passing through the reservoir. Emigration in 1965 was estimated at 408,000 fish, more than 100 percent of the estimated immigration (table 11). The range of the two estimates overlap, however. The first sockeye salmon appeared in the scoop traps 6 days after the first releases on March 15, 1965. The emigration was relatively short, beginning on March 21 and ending by the second week of May (fig. 8). Peak was during the week of April 4 to 10, when 175,000 fish are estimated to have left the reservoir.

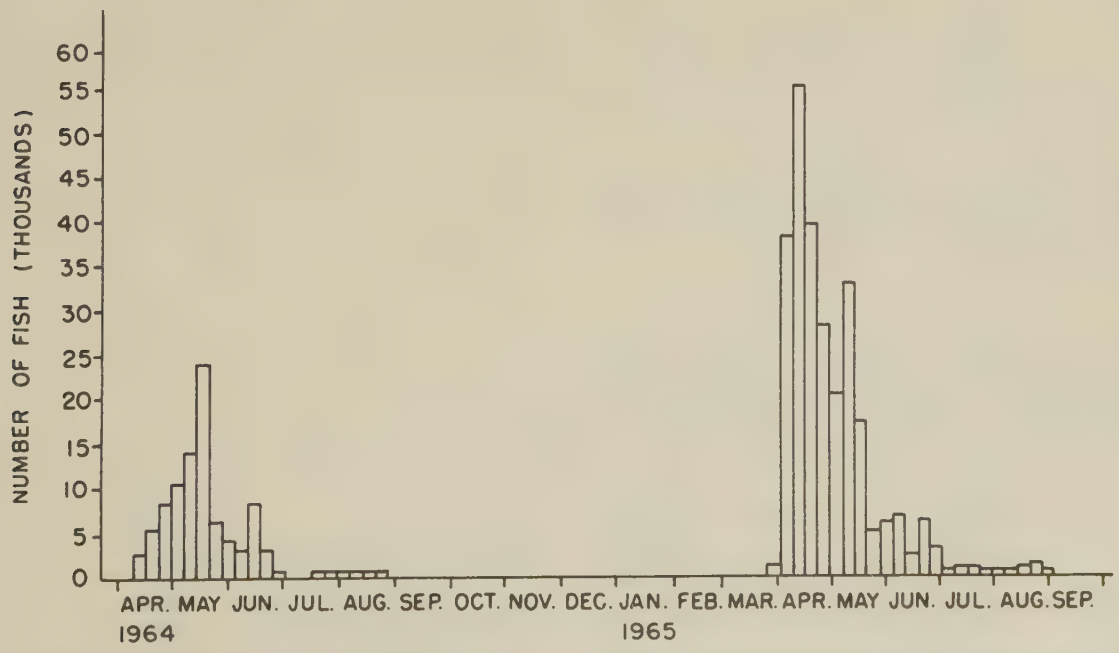

FIGURE 6.—Estimated emigration from Brownlee Reservoir of juvenile hatchery-reared fall chinook salmon from the Snake River, April 1964 to September 1965.

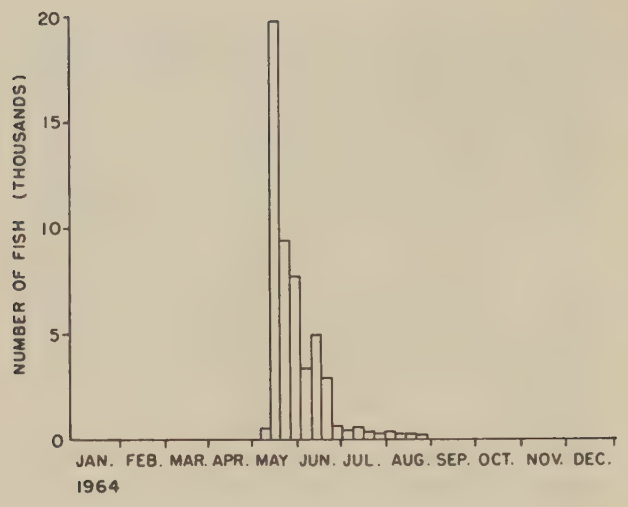

FIGURE 7.—Estimated emigration from Brownlee Reservoir of juvenile hatchery-reared coho salmon from the Snake River, 1964.

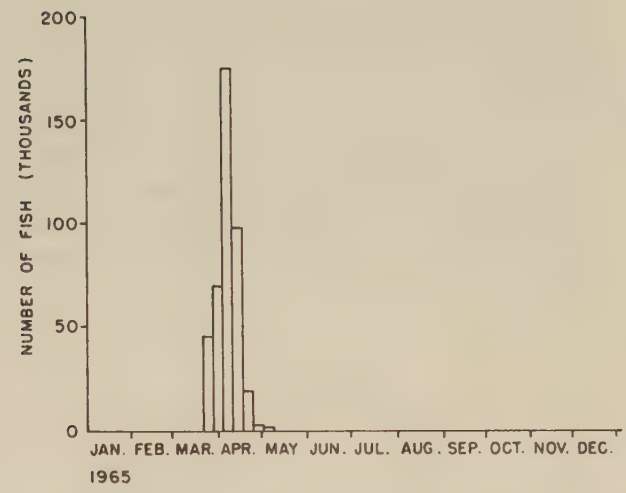

FIGURE 8.—Estimated emigration from Brownlee Reservoir of juvenile hatchery-reared sockeye salmon from the Snake River, 1965.

TABLE 11.—*Estimated immigration of juvenile hatchery-reared coho and sockeye salmon into Brownlee Reservoir from the Snake River and estimated emigration from the Reservoir, May 1, 1963 to August 31, 1965*

Year class	Species	Estimated immigration	Year of emigration	Estimated emigration		Range of estimated emigration	
						Low	High
		Number		*Number*	*Percent*	*Number*	*Number*
1963	Coho	69,000	1964	51,600	75	37,900	72,600
1964	Sockeye	360,000	1965	[1] 408,000	[1] >100+	324,000	513,500

[1] Discrepancy between estimates of immigration and emigration probably due to differences in sampling techniques in Snake River and below Brownlee Reservoir.

EMIGRATION OF JUVENILE TROUT OF UNKNOWN ORIGIN

Because anadromous rainbow trout (steelhead) could not be separated from native and hatchery-reared resident rainbow trout, the data on emigration include all populations of rainbow trout. For the same reason, Krcma and Raleigh (1970) did not attempt to estimate immigrations of rainbow steelhead trout. Comparisons of emigration and immigration, therefore, were not possible. Juvenile rainbow trout emigrated from Brownlee Reservoir each year during this study. An estimated 24,800 rainbow-steelhead trout (table 12) left the reservoir from August 1963 through December 1964. The major emigrations were in May and June. In 1965, emigration was estimated at 73,600 fish, and the major outmigrations were in April and May.

TABLE 12.—*Estimates of emigration of juvenile native and hatchery-reared resident rainbow trout and anadromous rainbow (steelhead) trout from Brownlee Reservoir, May 1, 1963, to August 31, 1965*

Year of emigration	Estimated emigration	Range of estimate	
		Low	High
	Number	*Number*	*Number*
1963–64	24,800	17,900	35,000
1965	73,600	46,600	116,000

LENGTHS OF EMIGRANTS

The sizes of the juvenile fish in various stocks that emigrated from Brownlee Reservoir generally increased as the season progressed. The fork length of fall chinook salmon caught below the dam from August 1963 through December 1964 was 45 to 240 mm. (table 13). Two distinct length groups were evident from November 1963 through June 1964. The larger fish (age-group I) were from the 1963 year class of fall chinook salmon from the Snake River; these fish dominated the catch through March 1964. Beginning in April 1964, the smaller native spring chinook salmon of the 1963 year class and the hatchery releases of fall chinook salmon of the 1964 year class dominated. Holdover of fish was slight in 1965; the entire emigration was of native kokanee and spring chinook salmon (age-group I) of the 1964 year classes and hatchery releases of sockeye salmon (age-group I) and fall chinook salmon (age-group 0) of the 1964 and 1965 year classes.

Hatchery-reared coho salmon increased from an average length of 125 mm. (90–155 mm.) in May 1964 to 200 mm. (155–245 mm.) in August 1964 (fig. 9).

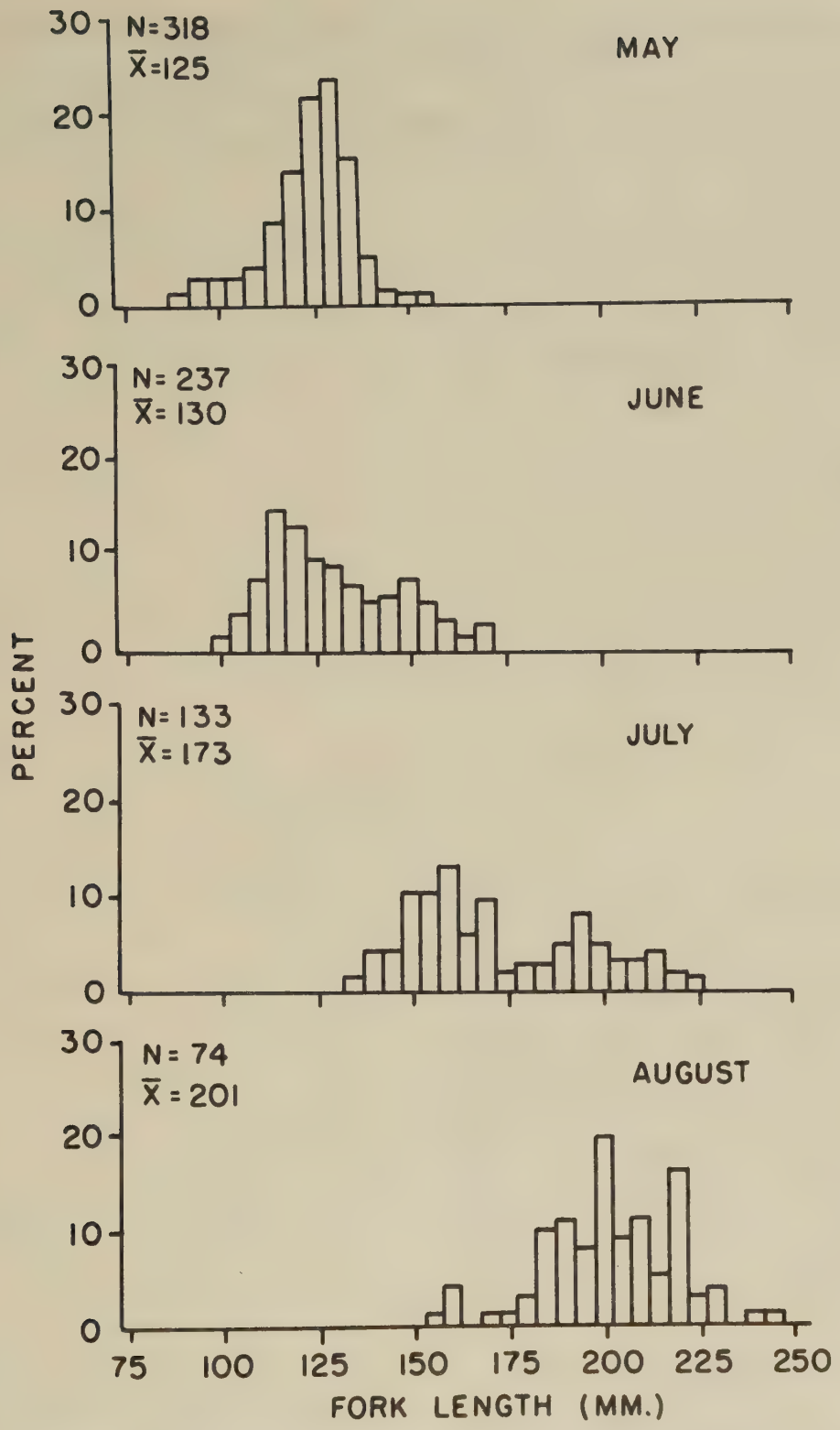

FIGURE 9.—Length-frequency distribution of 762 juvenile hatchery-reared coho salmon from the Snake River collected below Brownlee Dam, May 16 to August 31, 1964. (N=number of fish; $\bar{X}$ indicates average length.)

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TABLE 13.—*Length-frequency distribution of 5,697 juvenile fall chinook salmon from the Snake River collected below Brownlee Dam, August 1, 1963 to August 31, 1965*

Fork length	Number of fish by year and month											
	1963					1964						
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
Mm.												
240												
235												
230									1			
225									3	4		
220							2	13	6	1		2
215						7	8	29	16	2		3
210					1	13	25	49	25			3
205					1	41	47	45	24			2
200					7	48	55	34	10	1		1
195			1	2	13	43	26	17	9	2		
190				12	14	23	21	15	6	2		1
185				21	22	12	4	7	7	1		2
180			1	13	7	5	6	4	6	1		4
175			1	13	2	2		4	3			3
170	1	1		2	1	3	4	3				8
165	3	2	3	3	1	1	3	2				3
160	8	3	1	2			1	3				6
155	13	4	2									7
150	36	8								2	1	2
145	42	2								4	2	2
140	15								1	14	4	2
135	4							1	4	37	1	
130	1				1		1	4	11	86	16	
125	1				3	3	4	7	7	89	52	
120					2	3	6	10	12	66	111	
115					14	5	9	13	28	58	158	
110					7	3	12	15	50	65	131	
105					4	6	8	32	45	62	58	
100					2	1	10	29	51	76	20	
95				1	5		2	15	55	55	12	
90					1		4	6	56	43	1	
85							2		68	44	1	
80							2		74	32		
75									104	21		
70				1					102	8		
65									98	1		
60									31			
55									19			
50									1			
45									1			
Total	124	20	9	70	108	219	262	361	934	773	568	51

The average lengths of kokanee differed little in the early and late runs in 1964 (about 5 mm.), but in 1965 the average increased from 105 to 138 mm. during a 90-day period in June, July, and August (fig. 10).

Hatchery-reared sockeye salmon migrated through the reservoir during such a short period in 1965 that size of the fish changed little. The lengths of these fish were 75 to 170 mm. (fig. 11).

Length-frequency distributions for juvenile rainbow-steelhead trout are given in table 14. Lengths of trout below the dam were 65 to 368 mm. The larger fish probably were native rainbow trout rather than the offspring of anadromous steelhead trout.

EFFECT OF ENVIRONMENT ON EMIGRATION

The environment significantly affected the passage of juvenile salmon and trout through Brownlee Reservoir. In 1963, emigration from the reservoir was low when (1) reservoir drawdown in the spring was small, (2) the reservoir was filled early, and (3) maximum discharge was late.

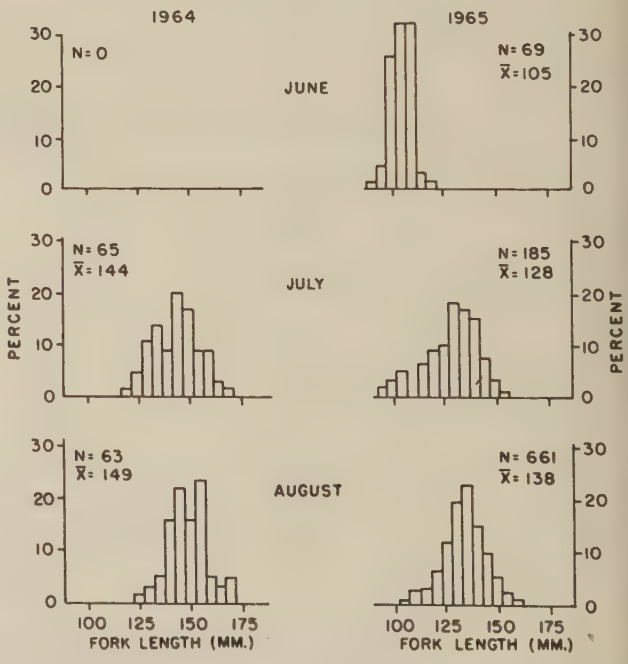

FIGURE 10.—Length-frequency distribution of 1,043 juvenile native kokanee from the Snake River collected below Brownlee Dam, 1964 and 1965. (N=number of fish; $\bar{X}$ indicates average length.)

TABLE 14.—*Length-frequency distribution of 1,381 juvenile rainbow-steelhead trout collected below Brownlee Dam, August 1, 1963 to August 31, 1965*

Length (mm.)	Number of fish by year and month											
	1963					1964						
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
350–359												
340–349											1	
330–339						2			1	1	2	1
320–329						2		1	3	1		
310–319						2		4	2	4	1	
300–309						4	5	8	14	5	1	
290–299	1			1		1	5	6	2	3		
280–289						1		1	1	2	2	
270–279								3				1
260–269	2								1		1	1
250–259			1							4		6
240–249	2	1							1	1		11
230–239	4							1	1	11		9
220–229	1							1	1	3	5	8
210–219								1	5	9	7	4
200–209								1	2	12	21	6
190–199								1	6	13	13	
180–189								1	2	19	15	1
170–179				1					9	29	7	
160–169							1	1	13	22	1	
150–159						1			14	15	1	
140–149									11	14		
130–139									9	8		
120–129									3	1		
110–119						1			3		1	
100–109									2	1		
90–99												
80–89									2		1	
70–79									2			
60–69												
Total	10	1	1	2	0	14	11	30	110	178	80	48

TABLE 14.—*Length-frequency distribution of 1,381 juvenile rainbow-steelhead trout collected below Brownlee Dam, August 1, 1963 to August 31, 1965*—Continued

Length (mm.)	Number of fish by year and month												
	1964					1965							
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
360–369									1		1		
350–359	1								1				
340–349								1	1	1			
330–339	2								2				
320–329			1							2	2	1	1
310–319								1	3	1	1		1
300–309								2	1				3
290–299	1							1	3	2			12
280–289	2							1	1	4	1		10
270–279	4								3	9	2		13
260–269	6							1	8	7	3	5	24
250–259	12							1	18	12	2	8	17
240–249	11								24	16	3	5	16
230–239	3	2						1	32	20	1	5	8
220–229	4								24	18	5	3	
210–219	1								34	17	7		2
200–209		1							19	18	5		
190–199									22	30	12	1	
180–189	1		1						32	25	15	2	
170–179				1					43	26	16		
160–169								1	27	22	11		
150–159									13	14	5		
140–149				1				1	9	4	1		
130–139					1				3	4	1		
120–129							1		1		3		
110–119										1	2		
100–109				1		1							
90–99			1						1			1	3
80–89			1							1			3
70–79													
60–69								1					
Total	48	3	4	3	1	2	0	12	326	254	99	31	113

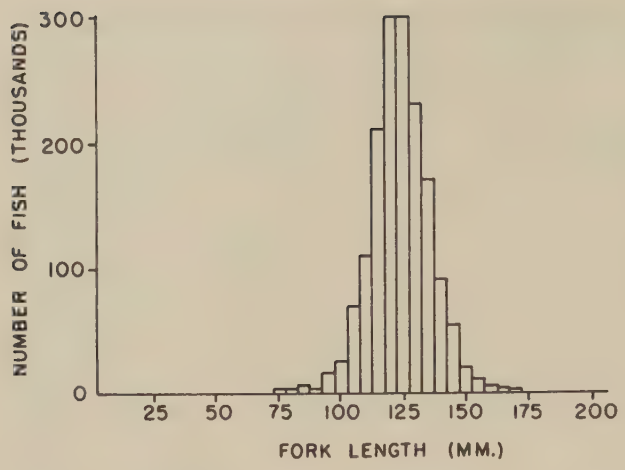

FIGURE 11.—Length-frequency distribution of 1,626 juvenile hatchery-reared sockeye salmon from the Snake River collected below Brownlee Dam, March 21 to May 13, 1965.

Emigration was notably more successful in 1964 and 1965 when the reservoir level was low through most of the downstream migration, and discharges were high during early and midspring.

Fish that entered the reservoir after the middle of June, as kokanee did in 1964 and 1965 (fig. 5), had poor success of passage. In both years, emigration of kokanee was less successful than that of other species of fish migrating earlier in the season. Kokanee did not enter the reservoir until late June when the reservoir was full and currents were weak and not clearly oriented in any direction. Those fish remaining in the reservoir through the summer encountered low oxygen concentrations (0–3 p.p.m.) below the thermocline and high water temperatures (24° C. or above) near the surface (Ebel and Koski, 1968). Few kokanee survived the harsh summer.

MORTALITY RELATED TO TURBINES

Because many fish were found dead in the scoop traps, the mortality attributable to the traps and the turbines was examined. A detailed investigation was beyond the scope of this study, but mortality was assessed at the turbine tailrace site in June 1965. During a 6-day period (June 1–6), all scoop traps were emptied twice daily—at 8:00 a.m. and 4:00 p.m. In a second 6-day period (June 7–12), all fish were removed as soon as they entered the traps (table 15). All fish caught during both periods were hatchery-reared chinook salmon of the 1965 year class.

Mortality during the two periods was as indicated in table 15: 88 percent of the fish were dead in the traps in the first period, and 16 percent were dead when they entered the traps in the second period. Because the fish were removed immediately in the second period, they died of causes other than trapping or handling.

To assess delayed mortality, samples of live fish taken from the traps during the second period were held in a holding tank in circulated water for an additional 24-hour period. Hatchery-reared chinook fingerlings collected in the reservoir above the dam were held with these fish to serve as a control (table 16). At the end of 24 hours, 67.5 percent of the fish taken from the traps and 17.5 percent of the control fish were dead. Thus, the delayed mortality of fish passing through the turbines was 50 percent.

Thus, on the average under test conditions, 16 of every 100 fish passing the sampling site were already dead. Of the 84 survivors, 42 died within 24 hours, which indicated a total turbine-related mortality of 58 percent.

TABLE 15.—*Mortality of juvenile hatchery-reared chinook salmon taken by scoop traps at the turbine tailrace sampling site, June 1–12, 1965*

Date	Turbine discharge	Water temperature	Fish in total catch	Mortality	
	M.³/sec.	*°C.*	*Number*	*Number*	*Percent*
Period A:[1]					
June 1	451	13	105	66	62
June 2	484	13	83	77	93
June 3	478	15	167	160	96
June 4	470	15	230	216	94
June 5	472	14	160	146	91
June 6	410	15	323	274	85
Totals			1,068	939	88
Period B:[2]					
June 7	547	15	148	26	18
June 8	523	15	65	12	19
June 9	440	15	23	1	4
June 10	433	15	18	1	5
June 11	423	16	4	1	25
June 12	334	17	15	2	13
Totals			273	43	16

[1] Normal operating conditions. Trap emptied at 8:00 a.m. and 4:00 p.m. daily.
[2] Fish removed from trap immediately upon entry.

TABLE 16.—*Delayed mortality of juvenile hatchery-reared chinook salmon taken from the tailrace scoop traps, June 7–12, 1965*

Group	Fish in trap	Mortality at the end of 24 hours	
	Number	*Number*	*Percent*
Experimental	83	56	67.5
Control	103	18	17.5

SUMMARY AND CONCLUSIONS

Estimates of emigration of juvenile salmon and trout from Brownlee Reservoir from July 1963 through August 1965 were based on catches in floating scoop traps below Brownlee Dam and on estimates of efficiency of the traps.

Emigration of native fall chinook salmon of the Snake River was estimated at 15 percent of immigration into the Reservoir in 1963 (1963 year class). Hatchery-reared fall chinook salmon (age-group 0) were planted in the Snake River in 1964 and 1965. Estimates of emigration were 85 percent of immigration in 1964 and 100 percent in 1965.

Emigration of native spring chinook salmon (Eagle Creek and the Weiser River) was estimated at 16 percent of immigration in 1964 and at 51 percent in 1965.

Emigration of native kokanee of the Snake River system was estimated at 38 percent of immigration in 1964 and at 10 percent in 1965.

Hatchery-reared coho and sockeye salmon were planted in the Snake River in 1964 and 1965, respectively. An estimated 75 percent of the coho salmon (1963 year class) that entered the reservoir in 1964 passed through. Emigration of sockeye salmon (1964 year class) in 1965 was estimated at 100 percent of immigration.

Because anadromous rainbow trout (steelhead) could not be separated from populations of native and hatchery-reared resident rainbow trout, I did not compare emigrations and immigrations. About 24,800 rainbow trout left the reservoir from August 1963 through December 1964. Emigration was estimated at 73,600 fish in 1965.

The environment in the reservoir during the time of outmigration clearly affected success of passage. In general, fish that entered the reservoir early in the spring, when the reservoir was drawn down and water temperature and oxygen concentrations were favorable, passed through more successfully than did those that entered during the summer, when water temperatures were high, currents were weak, and concentrations of oxygen were low.

The fish of the various stocks that emigrated from Brownlee Reservoir showed a general increase in length as the season progressed.

The following general conclusions were reached:

1. Downstream migrants that entered the reservoir early in the season passed through more successfully than those that entered later.
2. Emigration was more successful when the reservoir level was low during the time of migration than when the reservoir was filled before completion of the migration.
3. Because of time of emigration, size of the fish at time of entry into the reservoir, and the shorter distance traveled by the fish, one would expect what happened: Progeny of native spring chinook salmon migrated through the reservoir more successfully than native fall chinook salmon.

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CHARACTERISTICS OF SOME LARVAL BOTHID FLATFISH, AND DEVELOPMENT AND DISTRIBUTION OF LARVAL SPOTFIN FLOUNDER, *CYCLOPSETTA FIMBRIATA* (BOTHIDAE)[1]

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ABSTRACT

Pertinent literature on larval flatfish of the family Bothidae and some of the characters helpful in identifying these larvae are discussed. Helpful characters are of two types; transitory, those which are lost, and permanent, those which are retained. Transitory characters include larvae pigmentation, elongate dorsal and pelvic fin rays, and spination; permanent characters include meristic counts, placement of pelvic fin bases and fin rays, and caudal osteology.

Developmental changes in general growth patterns, formation of fins, larval spination, pigmentation, migration of the right eye, and sequence of ossification based on 171 larvae (1.7–14.5 mm. SL) collected off the south Atlantic coast of the United States is presented. Several sizes of larvae showing spination, pigmentation, and elongate fin rays are illustrated, and one illustration shows the degree of ossification.

Spawning appears to occur between April and October in waters of about 50 m. or less. Fertilized eggs have not been seen, but their size at hatching is estimated to be about 1.5 mm.

Five families of flatfish occur off the southeastern coast of the United States (Bothidae, Scophthalmidae, Pleuronectidae, Soleidae, and Cynoglossidae). Species of bothids are common in the inshore waters south of Cape Hatteras, N.C., and are more numerous (13 genera and 49 species) than are species of the other four families (Cynoglossidae, 1 genus and about 15 species; Soleidae, 3 genera and 5 species; Pleuronectidae, 1 genus and 3 species; Scophthalmidae, 1 genus and 1 species).

The spotfin and other flounders discussed in this paper are taken in industrial fish catches or are caught incidentally in shrimping. Of these flounders, only the fluke (*Paralichthys*) is removed from the catch and its flesh utilized. Flukes are also fished for sport or commercially along much of the east and Gulf coasts of the United States. Several other species of large flounders may be fished commercially in the future if stocks of sufficient size can be found.

Larvae of flatfish along the southeastern coast of the United States are poorly known; however, a few authors have illustrated and described some of these fish taken off North Carolina. Goode and Bean (1896) identified an *Ancylopsetta dilecta* larvae (listed as *Notosema dilecta*, Bothidae); Hildebrand and Cable (1930) had larvae of *Paralichthys* (Bothidae); and Deubler (1958) showed the postlarvae of *Paralichthys*. Hildebrand and Cable illustrated and described larvae of *Symphurus plagiusa* (Cynoglossidae) in 1930, and the larvae of *Trinectes maculatus* (listed as *Achirus fasciatus*, Soleidae) in 1938 from off North Carolina.

I discuss the literature pertaining to the larvae of *Syacium* (Bothidae) in some detail, because of the many similar external features between the larvae of *Cyclopsetta* and *Syacium*. Both genera have many elongate dorsal and pelvic fin rays, a single sphenotic spine, and heavy preopercular spines, but larvae of *Cyclopsetta* have more numerous elongate dorsal fin rays, and the sphenotic and preopercular spination is smaller.

This paper reports on development of larvae of spotfin flounder, *Cyclopsetta fimbriata*, that U.S. Fish and Wildlife Service vessels *Theodore N. Gill* and *Oregon* collected off the south Atlantic coast of the United States (fig. 1). It describes growth changes in the head length, body depth, eye diameter, snout length, and upper and lower

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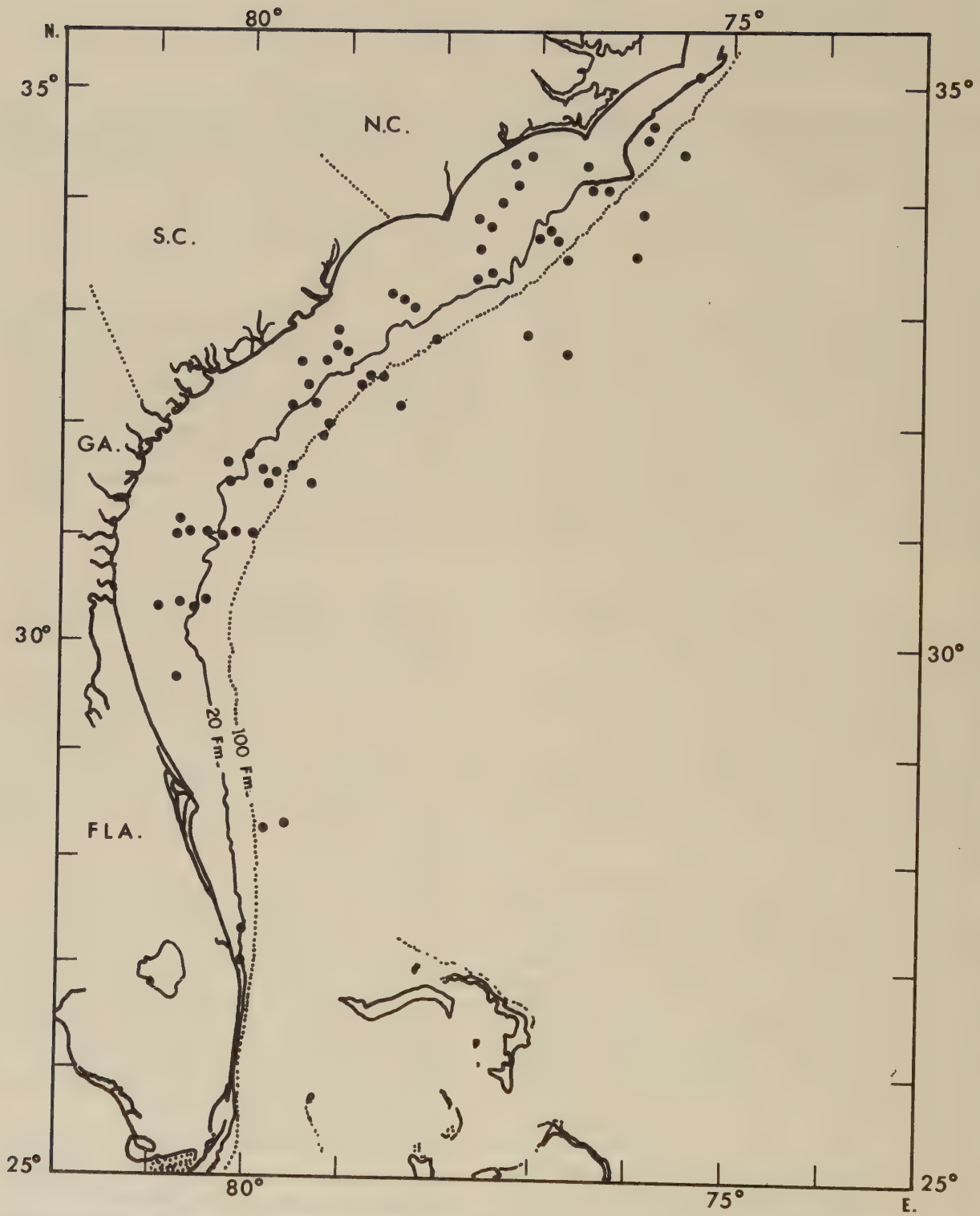

FIGURE 1.—Collection sites of *Cyclopsetta fimbriata* larvae from cruises of U.S. Fish and Wildlife Service vessels *Gill* and *Oregon*.

jaw lengths, and the development of fins, spination, pigmentation, sequence of ossification, and migration of the right eye.

REVIEW OF PERTINENT LITERATURE CONCERNING BOTHID LARVAE

In their description of *Ancylopsetta dilecta* (three-eyed flounder), Goode and Bean (1896) did not mention the larva they illustrated or any of its larval characters. The following characters are taken from the illustration: about 70 dorsal fin rays, the 9 anteriormost elongate; about 60 anal fin rays; 6 pelvic fin rays, the first three are elongate and extend almost to the caudal peduncle; ocular-side pelvic fin on median line; small eye; large mouth; origin of dorsal fin anterior to anterior edge of eyes; migrating (right) eye appears to move under the dorsal fin or through the head. All of these characters except the number of fin rays are present on large larvae of *Cyclopsetta*. Well-developed preopercular spines and a single sphenotic spine are present on larval *Cyclopsetta* but are not shown on Goode and Bean's illustration. Despite the lack of spines on their illustration, I believe their specimen is a *Cyclopsetta*.

In *Ancylopsetta*, the ocular-side pelvic fin is above the median line; the origin of the dorsal fin is above the anterior part of the eye, not in advance of it; the eyes are large, and the right side eye probably migrates over the median dorsal ridge anterior to the origin of the dorsal fin, not under it. I do not know if larvae of *Ancylopsetta* have elongate dorsal and pelvic fin rays.

Many species of Bothidae have elongate dorsal and pelvic fin rays in the larval stage, but larvae of *Syacium* are the only other bothid larvae to have numerous elongate dorsal (more than five) and pelvic (generally three) fin rays. *Symphurus* larvae (family Cynoglossidae) also have elongate dorsal rays, that can number up to seven. The numbers of dorsal and anal fin rays that Goode and Bean (1896) show are too low for *Syacium*, and the elongate pelvic fin rays they show are too long for *Syacium*.

I am unaware of any published accounts of *Ancylopsetta* larvae except those in which *Syacium*, *Cyclopsetta*, *Citharichthys*, or *Etropus* larvae have been misidentified as *Ancylopsetta*. Kyle (1913) described and illustrated (fig. 27) a 6- to 7-mm. larva he called *Ancylopsetta* sp. Regan (1916) illustrated (plate 9, fig. 3) a specimen identified as *A. quadrocellata* that he said resembles Kyle's (1913) *Ancylopsetta;* Regan's second illustration (plate 9, fig. 4) is a 4-mm. larva that he called *Ancylopsetta* sp. Both of Regan's (1916) larvae as well as the larva figured by Kyle (1913) are larvae of *Syacium*. Aboussouan (1968) discussed in detail the relation of Kyle's (1913) *Ancylopsetta* and Regan's (1916) *Ancylopsetta* to *Syacium*. Dannevig (1919) and Hsiao (1940) recorded *Ancylopsetta* larvae from eastern Canada and along the outer edge of Georges Bank that are similar to Kyle's *Ancylopsetta* sp. and these also are larvae of *Syacium*—warm-water species of vertebrates and invertebrates in this area are not uncommon (Bigelow, 1926, and Colton, 1961). Pearson (1941) listed *Ancylopsetta* sp. in plankton collections from Chesapeake Bay, but these are probably *Etropus* or *Citharichthys*. Pearson (1941: 84) stated, "The most characteristic features of the two fish are the pronounced elongation of the first two dorsal rays, the latter reaching nearly a quarter the length of the body, and the elongation of one of the ventral fins into a filament extending to the vent." These larval characters are found on larvae of *Etropus* and *Citharichthys*, and species of these two genera are known from Chesapeake Bay. *Cyclopsetta* and *Syacium* have not been reported north of Cape Hatteras, N.C., except for larvae of *Syacium* referred to as *Ancylopsetta* by Dannevig (1919) and Hsiao (1940).

Known larvae of *Etropus* have 2 elongate dorsal fin rays, and *Citharichthys* larvae have 0 to 3 elongate dorsal fin rays (5–10 in *Cyclopsetta* and *Syacium*) and 1 or 2 elongate pelvic fin rays (3 in *Cyclopsetta* and *Syacium*).

S. guineensis (Bleeker, 1862) probably is a synonym of *S. micrurum* Ranzani 1840; if so, the larvae described by Aboussouan (1968) from off Dakar are those of *S. micrurum*. Norman (1934) listed *S. guineensis* in the synonymy of *S. micrurum* and gave its distribution as "Atlantic coast of tropical America from Florida to Rio de Janeiro, tropical West Africa." Distinguishing between adult *S. guineensis* and *S. micrurum* is difficult, and they are separated by their distribution; *S. guineensis* off west Africa and *S. micrurum* off Florida, the Antilles, through the Gulf of Mexico and the Caribbean Sea, and off the Atlantic coast of South America to Rio de Janeiro.

Three species of *Syacium* occur in the western North Atlantic. *S. papillosum* (Linnaeus, 1758) and *S. micrurum* are difficult to separate as juveniles and can be separated as adults only by the width of the interorbital space. All other meristic and morphometric characters overlap. *S. gunteri* Ginsburg, 1933 can usually be separated from the other two species of *Syacium* in the western North Atlantic by the number of dorsal and anal fin rays. *Syacium papillosum* and *S. micrurum* rarely have fewer than 85 dorsal fin rays or fewer than 68 anal fin rays, whereas *S. gunteri* rarely has more than 84 dorsal fin rays and more than 67 anal fin rays (Gutherz, 1967).

Aboussouan's (1968) description of larval *S. micrurum* (listed as *S. guineensis*) is of greatest value for workers in the area off Dakar where only one species of *Syacium* is known. His paper is valuable in separating *Syacium* larvae from the larvae of other genera.

Aboussouan (1968) implied that Kyle's *Citharichthys* B. (Kyle, 1913; fig. 29) is a *Syacium* rather than a *Citharichthys*, but I disagree for the following reasons: At this stage of development larvae of *Syacium* have numerous elongated dorsal and pelvic fin rays but the known larvae of *Citharichthys* have only a few, if any, elongate fin rays; *S. gunteri* has fin ray counts similar to those given by Kyle for *Citharichthys*, but our larvae of *S. gunteri* have the heavy preopercular spination and the large sphenotic spine seen on the larvae of the other species of *Syacium;* the preopercular armature of *Syacium* is not reduced or blunted until the right side eye has reached the middorsal ridge or is turning onto the left side; the mouth of *Syacium* larvae is larger than that shown by Kyle, and the origin of the dorsal fin is more anterior; the larvae of several species of bothids have pigment patterns similar to *Citharichthys* B. I believe this specimen probably represents a *Citharichthys* or *Etropus*.

Paralichthys sp. and *P. olivaceous* larvae have been figured and described by Hildebrand and Cable (1930); Deubler (1958); Chang, Xo, and Sha (1965); and Okiyama (1967). These descriptions are based on larvae collected off the Atlantic coast of the United States, off Japan, and on laboratory-reared specimens. A high degree of similarity in the developmental pattern is noted except for Okiyama's *P. olivaceous*, which have longer elongate dorsal fin rays that seem to persist longer than the elongate dorsal fin rays on the larvae described by Chang et al. (1965). Characteristics common for the eggs and larvae of *Paralichthys* and a discussion of the relation between the migrating eye and the anterior portion of the dorsal fin are given by Chang et al. (1965).

Hippoglossina oblonga larvae have been illustrated and described by Agassiz (1879, listed as *Pseudorhombus oblongus*), Perlmutter (1939), and Miller and Marak (1962, listed as *Paralichthys oblongus*).

Citharichthys larvae have been figured by Ahlstrom (1965), and Kyle (1913, fig. 29) has illustrated what is probably a *Citharichthys* or *Etropus*.

Bothus larvae have been illustrated and described by Kyle (1913), Colton (1961), and Ochiai and Amaoka (1963) among others. These descriptions and figures of larvae collected off the Atlantic coast of the United States, the mid-Atlantic region, and off the Japanese coast show a high degree of similarity. All have only one elongate dorsal ray.

Chascanopsetta larvae have been illustrated and described by Kyle (1913) and Bruun (1937). Kyle was unable to refer his larva to any known Atlantic species, but Bruun placed it in *Chascanopsetta*.

Illustrations and descriptions of larvae in the closely related Scophthalmidae can be found in Smith (1904), Moore (1947), and Bigelow and Schroeder (1953).

MATERIALS AND METHODS

The original sampling procedures used on cruises of the FWS (U.S. Fish and Wildlife Service) vessel *Theodore N. Gill* were reported by Anderson, Gehringer, and Cohen (1956) and Anderson and Gehringer (1957).

Additional plankton samples were collected in January and June 1967 on cruises of the FWS vessel *Oregon*. Plankton and nekton samples were collected in depths of 14.6 to 45.7 m. (8–25 fath.) by 1-m. plankton and nekton nets (1-mm. mesh) and ½-m. plankton nets (1-mm. and 0.33-mm. mesh), which were towed for 15-minute periods.

A size series of specimens was cleared and stained by the procedure given by Taylor (1967).

All measurements were made with an eyepiece micrometer and a stereoscopic microscope and recorded to the nearest 0.01 mm.

MEASUREMENTS

Measurements used when working on larval flatfish require definition, because they differ significantly from those used on adult flatfish.

Standard length (SL) : Tip of snout to that point on notochord where dorsal flexture takes place (dorsal and anal finfolds have a slight indentation where the notochord turns dorsally, actinotrichia are visible in the caudal region of the finfold immediately posterior to this indentation) ; or tip of snout to base of median caudal fin rays if these rays are developed; or tip of snout to distal end of hypurals if caudal fin rays are developed.

Head length (HL) : Tip of snout to posterior edge of cleithrum on a horizontal line through center of left eye on small larvae; or tip of snout to origin of dorsalmost part of pectoral fin base; or tip of snout to posteriormost part of opercle on large larvae.

Body depth (BD) : When left side pelvic fin base is not developed, vertical depth is taken immediately posterior to the cleithrum; or from origin of left side pelvic fin base to dorsal margin of body (excluding finfold or rays).

Origin of pelvic fin base to cleithrum: Least distance from origin of pelvic fin base to ventral tip of cleithrum, both left and right sides.

Eye diameter (ED) : Horizontal distance across the left eye.

Upper jaw length (UJL) : Anterior tip of premaxillary to distal edge of maxillary.

Lower jaw length (LJL) : Symphysis of lower jaw to posterior edge of angular.

Snout length (SN) : Anteriormost part of premaxillary to anterior edge of left eye.

COUNTS

Dorsal, anal, caudal, and pelvic fin rays: Total number of fin rays in which the basal portion is distinguishable.

PROBLEMS ENCOUNTERED IN WORKING WITH LARVAL FLATFISHES

The wide variation in measurements and counts of larval flatfishes may be due to distortion by preservation or to differing rates of development. When killed and preserved the larvae often curl; the pectoral fins may harden in an extended position; the mouth may open and distort some head features; and the eyes often distend, shrink, or fall out. Larval fish are fragile, and fin rays are often broken, particularly the elongate rays. Poor preserving and collecting techniques often damage or distort specimens. Fresh, well-preserved, flatfish larvae can be held in place for examination by a cover slide, but older, softer, or poorly preserved material may be damaged if handled in this manner. Older, softer specimens are often difficult to measure; however, they are often partially or completely bleached, so that the fin rays and myomeres or vertebrae are easier to count than in the fresh firmer specimens. Much of the material from the *Theodore N. Gill* is soft, but that from more recent *Oregon* cruises is in excellent shape.

Pigment patterns fade and are lost in preservative, so a knowledge of when specimens were collected is important; also the rate of development is not the same for all individuals. Larvae collected over a wide geographic area and an extended period of time may show differing rates of development. Within a species, fishes that metamorphose at small sizes probably have different rates of development from those that metamorphose at larger sizes. These differences must be recognized when working with larval flatfish.

CHARACTERS USEFUL IN IDENTIFYING BOTHID LARVAE

Characters that can be used to identify bothid larvae fall into two categories: (1) transitory, those which are present during part or all of the larval period but eventually are lost and (2) permanent, those which develop during the larval period and are retained in the juvenile and adult stages.

Transitory characters include larval pigmentation, elongate fin rays, and head and body spination. Type and intensity of these transitory characters may be of generic or specific significance. Many of the bothid genera in the western North Atlantic have elongate dorsal and pelvic fin rays in the larval stages: *Paralichthys* (Hildebrand and Cable, 1930) ; some *Citharichthys* (Ahlstrom, 1965; *C. stigmaeus* has no elongate dorsal fin rays) ; *Syacium* (Aboussouan, 1968) ; *Bothus* and

Chascanopsetta (Kyle, 1913); and *Cyclopsetta* (Goode and Bean, 1896). Many bothid larvae in the western North Atlantic have spines. These are more frequently seen on the preopercular margin than on the head or body. Most bothids have a swim bladder during the larval stage. Those larvae with a protracted larval stage retain the swim bladder longest. The migrating eye moves over the middorsal ridge anterior to the origin of the dorsal fin or through the head between the dorsal fin and the supraorbital bars of the cranium.

Permanent characters include meristic counts, relation of the origin of the pelvic fin bases to each other and to the cleithrum, and the arrangement of the caudal fin rays with respect to the other caudal fin rays and the bones of the hypural plate. Size at metamorphosis is important in distinguishing between genera.

MERISTIC CHARACTERS

The most important characters for identification of bothid larvae are meristics. Myomeres, which correspond in number to vertebrae, are the first countable item to develop. Those near the anterior and posterior portions of the body are difficult to count in the early stage larvae. Abdominal vertebrae usually number 10, but can be 11 (*Chascanopsetta* has 16 or 17). Caudal vertebrae are much more variable, ranging from 23 to 42. The vast majority of bothid larvae have between 34 and 40 total vertebrae or myomeres. Dorsal and anal fin ray numbers are also variable and overlap widely between species of Bothidae. The adult complements of dorsal and anal fin rays are distinguishable in larval *C. fimbriata* by about 8-mm. SL (fig. 2). The rate of fin ray development and the fin ray numbers at the various sizes may have generic or specific value. Although much meristic overlap is evident among species of bothids, several species can be separated by meristic values.

PELVIC FIN

Pelvic fin characteristics helpful in determining a genus or generic group are: the position of the fin bases in relation to the median line, size of larvae when the left fin base and rays first appear, relation of the origins of the right and left side fin bases to the cleithrum, and the number of elongate fin rays.

Four of the 13 genera of bothids in the western North Atlantic (*Paralichthys*, *Ancylopsetta*, *Gastropsetta*, and *Hippoglossina*) have the left and right side fin bases above the median line; all other western North Atlantic bothid genera have the left side fin base on the median line and the right side fin base above the median line.

I have only seen *Paralichthys* of the four genera with left and right side pelvic fin bases above the median line. In *Paralichthys* the left side fin base does not appear until the larvae are about 7 mm.

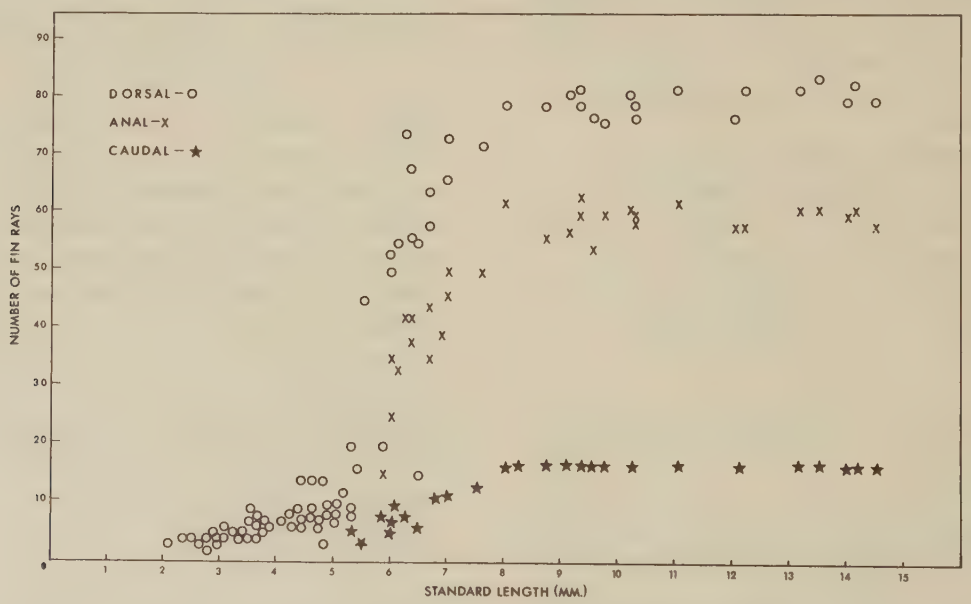

FIGURE 2.—Relation of number of dorsal, anal, and caudal fin rays to standard length of *Cyclopsetta fimbriata* larvae.

SL. I have not seen the larvae of *Ancylopsetta*, *Gastropsetta*, or *Hippoglossina*, but an illustration of a 5.7-mm. SL *Hippoglossina oblongus* by Perlmutter (1939); and illustrations of a 6.5-mm. specimen and a larger one by Agassiz, (1879, plate 9, figs. 4 and 5) do not show a left side pelvic fin. The pelvic fins of *H. oblongus* appear very much later than do the dorsal and anal fins (Agassiz, 1879).

At 5 mm. SL *Syacium*, *Cyclopsetta*, *Citharichthys*, and *Etropus* have a well-developed pelvic fin on the left side. The left side fin base appears at 2 to 3 mm. SL and is better developed than the right side base, which develops later.

I do not know at what size the pelvic fin bases first appear in *Engyophrys*, *Trichopsetta*, or *Monolene* (I have assigned larvae exceeding 8 mm. SL with well-developed pelvic fin bases to *Engyophrys* and *Monolene*). The origin of the left side fin base of adults is adjacent to the cleithrum or slightly anterior to it in *Engyophrys*, *Trichopsetta*, and *Monolene*, but the origin of the right side fin base is slightly posterior to the cleithrum.

The origins of the left and the right side pelvic fin base are posterior to the cleithrum in *Paralichthys*, *Ancylopsetta*, *Gastropsetta*, *Hippoglossina*, *Syacium*, *Cyclopsetta*, *Citharichthys*, and *Etropus*. In *Bothus* and *Chascanopsetta* the origin of the left side pelvic fin base is on the urohyal, which is well in advance of the cleithrum. The right side fin base of *Bothus* and *Chascanopsetta* is short, and its origin is well posterior to the cleithrum.

CAUDAL OSTEOLOGY

From late stage larvae to adults, the bothids show a correlation between caudal osteology and position of the pelvic fin bases (table 1). Species of *Paralichthys*, *Ancylopsetta*, *Gastropsetta*, and *Hippoglossina* have the dorsalmost principal caudal fin ray associated with an epural; the ventralmost principal caudal fin ray has a spur associated with it, and it is associated with the haemal spine of the penultimate vertebra. The count of principal caudal fin rays in this group, starting with the epural and ending with the haemal spine of the penultimate vertebra, is 1–2–6–4–3–1 or 1–2–6–5–2–1 in *Paralichthys*. In these genera neither of the plevic fin bases is on the median line and the origins of both pelvic fin bases are well behind the cleithrum.

Species of *Syacium*, *Cyclopsetta*, *Citharichthys*, and *Etropus* have all 17 principal caudal fin rays associated with the four hypural elements. The dorsal-to-ventral count of principal caudal fin rays on each hypural is 4–5–4–4. In these genera the left side pelvic fin base is on the median line, and its origin is well behind the cleithrum.

TABLE 1.—*Four generic groups which show a relation between the origins of the pelvic fin bases and number of principal caudal fin rays associated with caudal elements*

[Asterisks indicate the genera for which I have no identified larvae]

Genera	Pelvic fin (P^2)	Number of principal caudal fin rays associated with caudal elements
Paralichthys	Neither pelvic fin base on median line, both short-based; origins well behind cleithrum.	1-2-6-5-2-1
*Ancylopsetta**		
*Gastropsetta**		1-2-6-4-3-1
*Hippoglossina**		
Syacium	Ocular-side P^2 base on median line; origin posterior to cleithrum. Blind-side P^2 base above median line; origin posterior to cleithrum.	4-5-4-4
Cyclopsetta		
Citharichthys		
Etropus		
Engyophrys	Ocular-side P^2 base on median line; origin slightly anterior to or below cleithral tip. Blind-side P^2 base above median line; origin posterior to cleithrum.	1-3-5-4-3-1
*Trichopsetta**		
Monolene		
Bothus	Ocular-side P^2 base on median line, extending onto urohyal; origin anterior to cleithrum. Blind-side P^2 base above median line, short-based; origin posterior to cleithrum.	1-4-4-3-4-1
*Chascanopsetta**		

Species of *Engyophrys*, *Trichopsetta*, and *Monolene* have the dorsalmost and ventralmost principal caudal fin rays associated with the neural and haemal spines of the penultimate vertebra and have a count of 1–3–5–4–3–1. In these genera the left side pelvic fin base is on the median line and its origin is slightly anterior to the cleithral tip and to the origin of the right side base.

In *Bothus* and *Chascanopsetta* the count of principal caudal fin rays associated with the caudal elements is 1–4–4–3–4–1, starting at the neural spine and ending at the haemal spine of the penultimate vertebra. In *Bothus and Chascanopsetta* the left side pelvic fin base is on the median line and its origin is on the urohyal, on the right side the base is short, above the median line, and its origin is behind the cleithrum.

The number of principal caudal fin rays associated with caudal elements shows some variation, because a fin ray may be supported in part by two elements, such as hypurals, epurals, or neural or haemal spines.

DEVELOPMENT OF *CYCLOPSETTA FIMBRIATA* LARVAE

No information is available on the fertilized eggs or the yolk sac larvae of *C. fimbriata;* however, I do have certain observations on the larger larvae, including their identification, patterns of general growth, formation of fins, spination, pigmentation, migration of eyes, and sequence of ossification.

IDENTIFICATION OF LARVAE

Larvae of *C. fimbriata* are identifiable at very small sizes. The smallest larva in my sample (1.72 mm. SL) has a large head with a well-developed mouth. Hatching size is probably about 1.50 mm. SL or slightly smaller. Larvae of this species have two prominent transitory features (they may be generic) that are readily seen on the smallest larvae (fig. 3) : a small, single spine on the sphenotic region of the cranium and several small single spines on the preopercle (*Syacium* has larger sphenotic and preopercular spines). These spines persist throughout the larval stages (figs. 3–7) and are still evident during metamorphosis (that period when the eye is migrating). No fin rays are discernible in the finfold of the smallest larva (1.72 mm. SL). At about 2.10 mm. SL the first three elongate dorsal fin rays appear. Elongate dorsal fin rays (8–11 in the large larvae) persist throughout the larval stages (figs. 4–7). At about 3.00 to 3.30 mm. SL one to three elongate pelvic fin rays appear (fig. 4) and persist throughout the larval stages (figs. 4–7).

The right side eye is migrating in the largest larva in my sample (14.51 mm. SL). The dorsal edge of the migrating eye is above the middorsal ridge of the cranium. During metamorphosis the eye moves under the dorsal fin which is attached anteriorly to the ethmoid region of the cranium. The migrating eye had not yet begun to turn onto the left side, but it appeared about ready to move under the dorsal fin. Elongate dorsal and pelvic fin rays and head and preopercular spination persist (fig. 7).

Four transitory larval features help differentiate *C. fimbriata* and *Syacium* larvae from all other bothid larvae found along the southeastern coast of the United States: (1) a single spine in sphenotic region of the cranium, (2) several single preopercular spines, (3) relatively high numbers of elongate anterior dorsal fin rays, and (4) three elongate pelvic fin rays (figs. 3–7). Compared to *Cyclopsetta*, *Syacium* has larger and heavier spines, fewer elongate dorsal fin rays, and relatively shorter elongate pelvic fin rays. The sphenotic spine is surrounded by concentric rings on large *Cyclopsetta* larvae but by a crenulated cap on *Syacium* larvae. The origins of the pelvic fin bases in relation to each other and to the cleithrum and the transitory larval characters provide the generic identity of *Cyclopsetta* larvae.

Three species of *Cyclopsetta* occur in the western North Atlantic Ocean (Gutherz, 1967). *C. fimbriata* is the only species known from the Atlantic coast of the United States, *C. decusata* is known only from the type, and *C. chittendeni* is found along the coast of the United States only in the Gulf of Mexico. The distribution of these species excludes all known species of *Cyclopsetta* except *fimbriata* from consideration for my larvae.

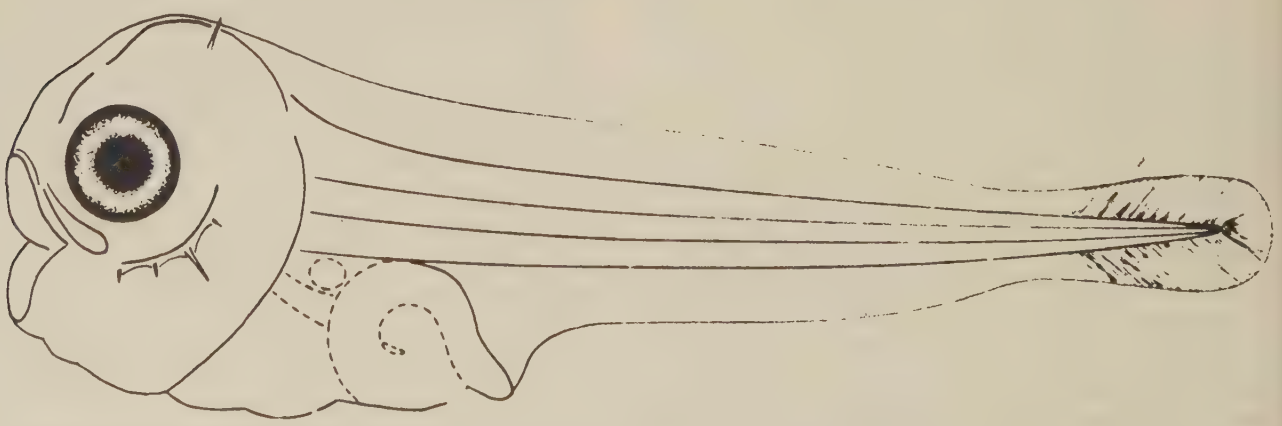

FIGURE 3.—Larva of *Cyclopsetta fimbriata*, 1.89 mm. SL. Note sphenotic and preopercular spination. Pectoral fin is omitted to show swim bladder and gut.

GENERAL GROWTH PATTERNS

Head length and body depth show a uniform rate of increase with standard length throughout the size range of my sample (figs. 8–9).

Upper jaw length shows a uniform rate of increase with standard length in larvae longer than about 4 mm. SL, but smaller larvae have a faster rate of increase (fig. 10).

Lower jaw length increases at a uniform rate with standard length in larvae between about 4 and 13 mm. SL; but larvae smaller than about 4 mm. SL and longer than 13 mm. SL have a faster rate of increase (fig. 11).

Snout length increases only slightly in specimens up to about 2.7 mm. SL; between about 2.7 and 4 mm. SL snout length increases at its fastest rate; and larvae larger than about 4 mm. SL have a uniform but slower rate of increase with standard length (fig. 12).

Eye diameter increases at a uniform rate with standard length in larvae longer than about 3.5 mm. SL; the rate is faster in smaller larvae (fig. 13). Eye diameter as a percentage of head length decreases throughout the size range in my sample (fig. 14); the fastest decrease is between head lengths of about 0.5 and 1.5 mm. (1.8 to about 4 mm. SL).

FIGURE 4.—Larva of *Cyclopsetta fimbriata*, about 3.0 mm. SL. Note sphenotic and preopercular spination, elongate dorsal and pelvic fin rays, and pigmentation. Pectoral fin is omitted to show swim bladder, gut, and pigmentation on dorsal portion of swim bladder and gut.

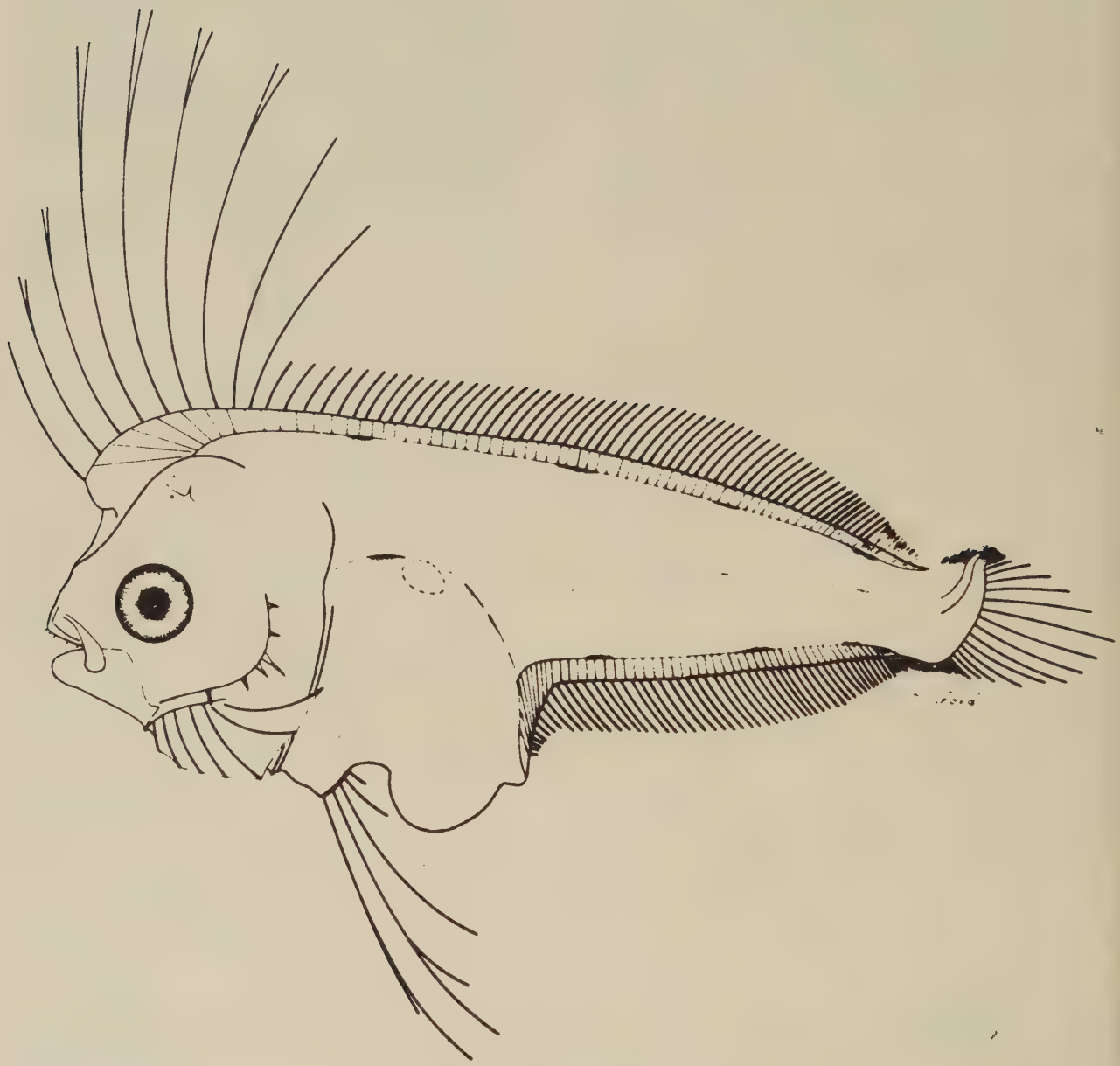

FIGURE 5.—Larva of *Cyclopsetta fimbriata*, 6.9 mm. SL. Note sphenotic and preopercular spination, elongate dorsal and pelvic fin rays, and pigmentation. Pectoral fin is omitted.

FIGURE 6.—Larva of *Cyclopsetta fimbriata*, 12.9 mm. SL. Note sphenotic and preopercular spination, elongate dorsal and pelvic fin rays, pigmentation, and area under anterior portion of the dorsal fin through which the right side eye will migrate.

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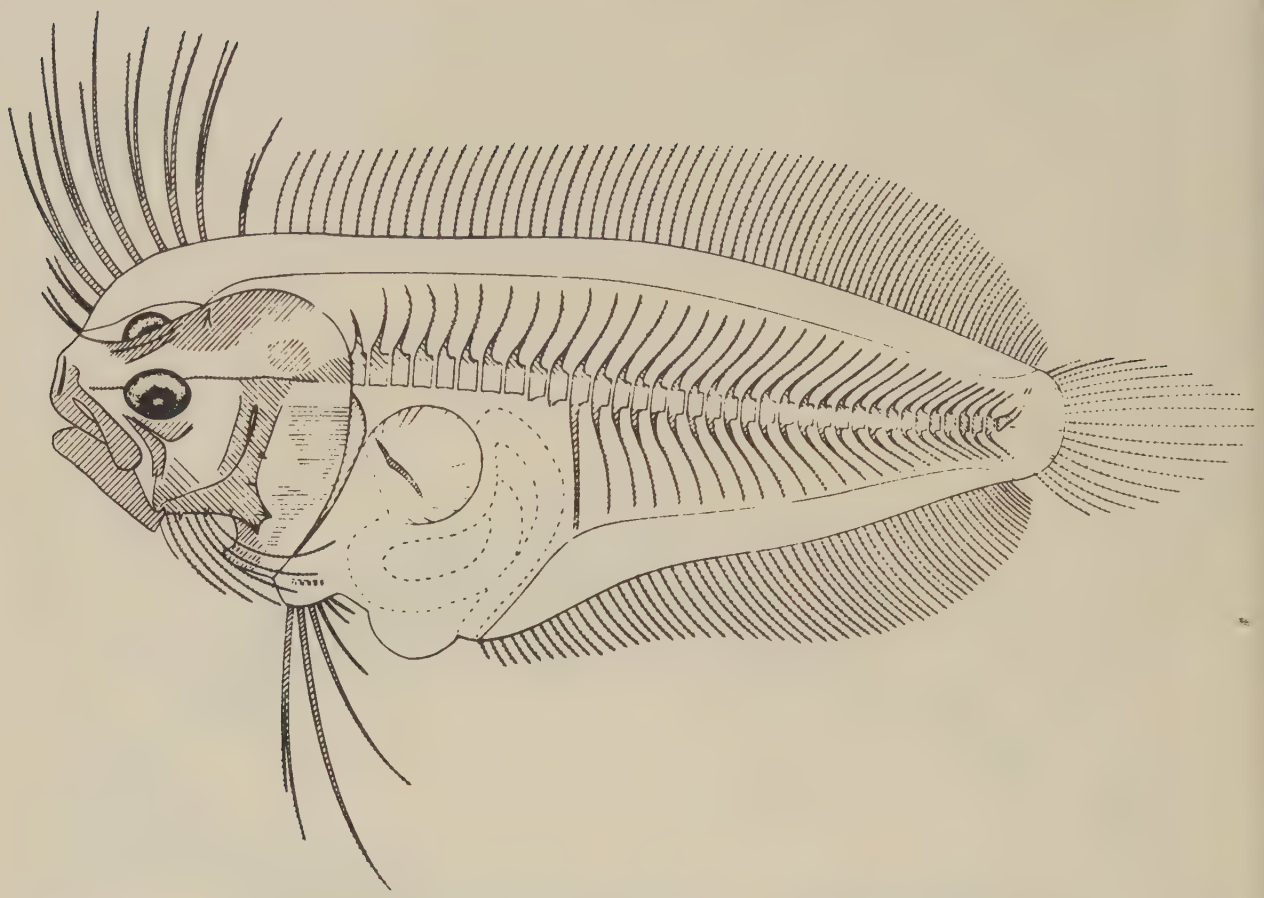

FIGURE 7.—Larva of *Cyclopsetta fimbriata*, 14.0 mm. SL. Larva has been cleared and stained, and all bone that has absorbed alizarin red S is shaded. Note sphenotic and preopercular spination, elongate dorsal and pelvic fin rays, right side eye under anterior part of dorsal fin will migrate through head. Ossification is not yet complete.

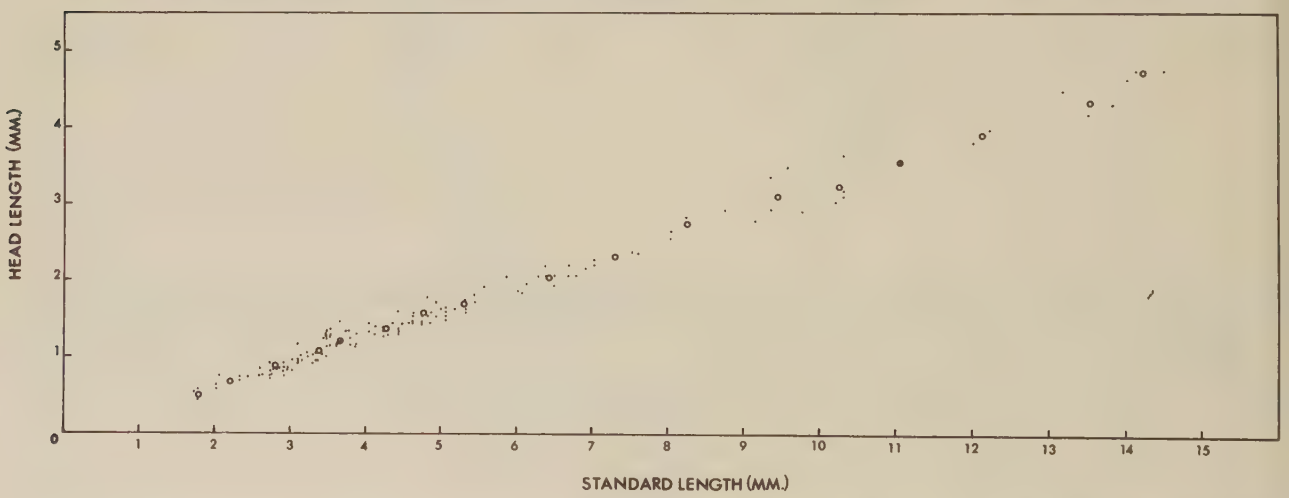

FIGURE 8.—Relation of head length to standard length of *Cyclopsetta fimbriata* larvae. Dots represent individual specimens, and open circles represent means (see app. tables 1 and 2).

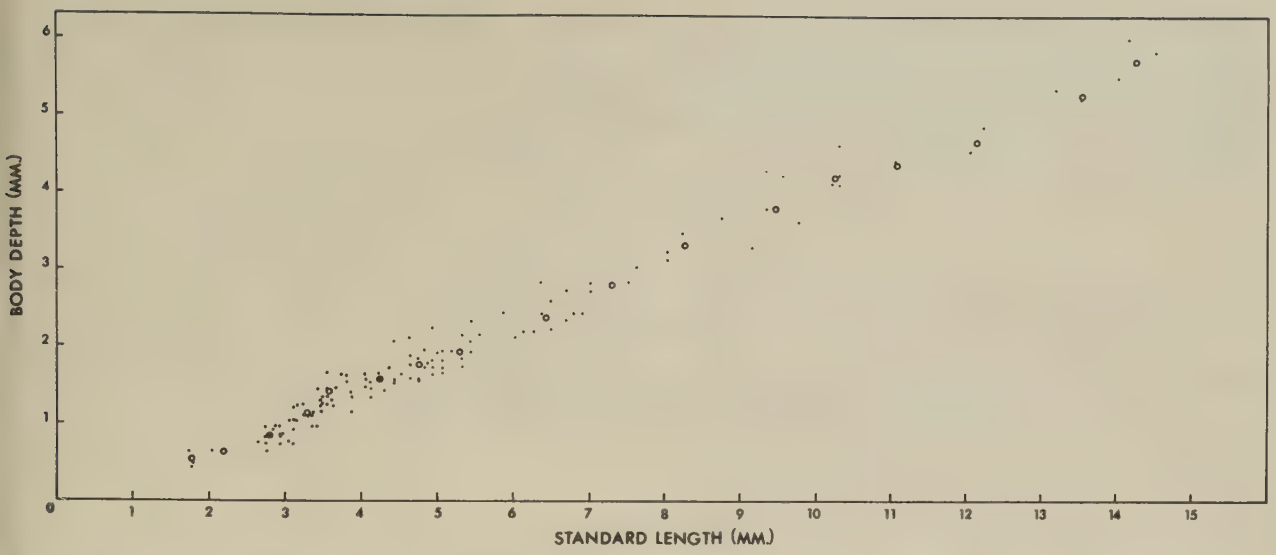

FIGURE 9.—Relation of body depth to standard length of *Cyclopsetta fimbriata* larvae. Dots represent individual specimens, and open circles represent means (see app. tables 1 and 2).

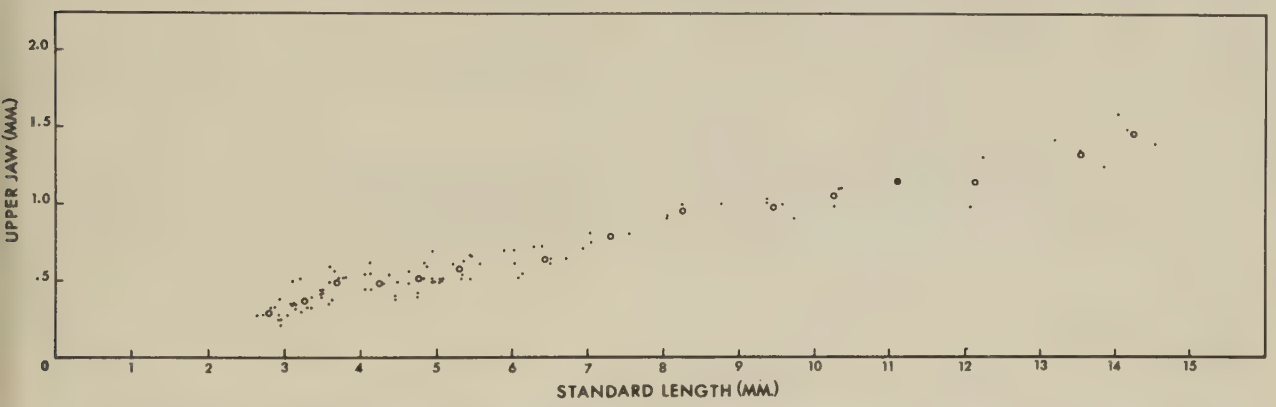

FIGURE 10.—Relation of upper jaw length to standard length of *Cyclopsetta fimbriata* larvae. Dots represent individual specimens, and open circles represent means (see app. tables 1 and 2).

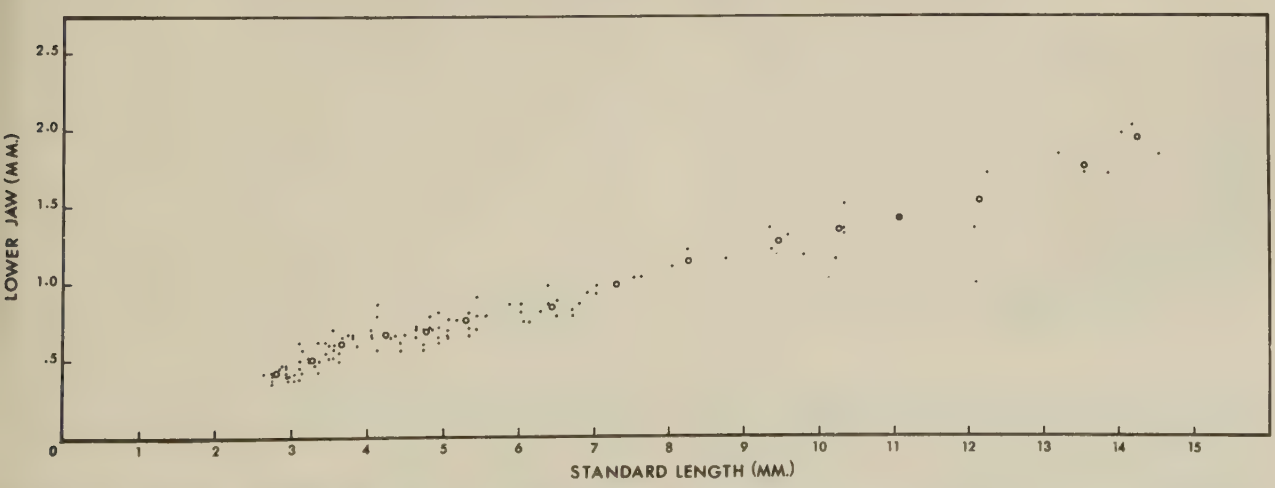

FIGURE 11.—Relation of lower jaw length to standard length of *Cyclopsetta fimbriata* larvae. Dots represent individual specimens, and open circles represent means (see app. tables 1 and 2).

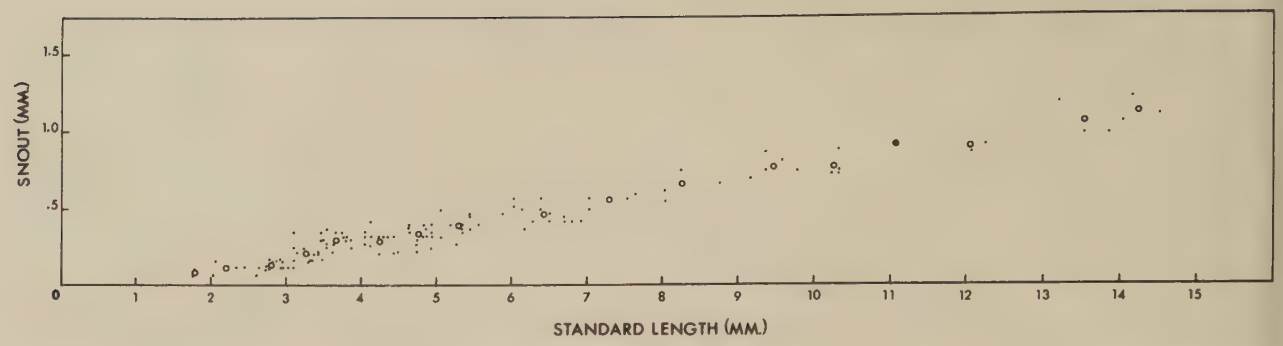

FIGURE 12.—Relation of snout length to standard length of *Cyclopsetta fimbriata* larvae. Dots represent individual specimens, and open circles represent means (see app. tables 1 and 2).

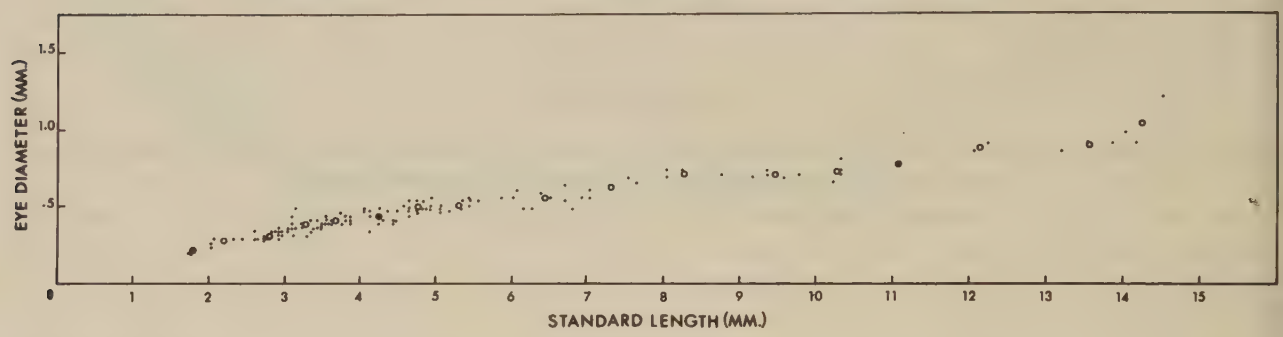

FIGURE 13.—Relation of eye diameter to standard length of *Cyclopsetta fimbriata* larvae. Dots represent individual specimens, and open circles represent means (see app. tables 1 and 2).

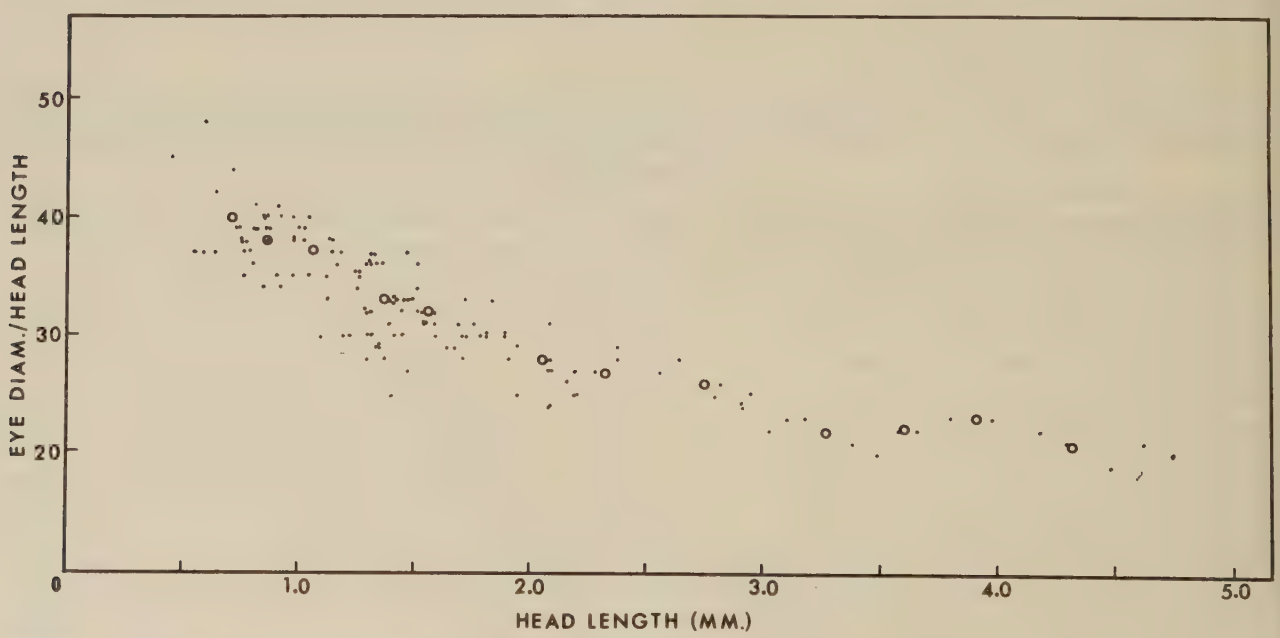

FIGURE 14.—Decrease in eye diameter relative to head length of *Cyclopsetta fimbriata* larvae. Dots represent eye diameter as percentage of head length of individual specimens, and open circles represent means (see app. tables 1 and 2).

Gill rakers begin to develop as elevations on the dorsal surface of the ceratobranchial. They are first seen when the larvae are about 8 mm. SL. Four or five lower-limb gill rakers are first seen on larvae about 9 mm. SL. They are short, blunt, well separated, and located on the ceratobranchial. By 10.0 mm. SL the number of lower-limb gill rakers has increased to seven and they are found on the ceratobranchials and hypobranchials. The adult complement of 8 to 10 gill rakers on the lower limb is reached at about 13.5 mm. SL. Gill rakers are first seen on the epibranchial in 13.5 mm. SL larvae, which have a single gill raker located immediately above the angle.

FIN FORMATION

In the development of *C. fimbriata* the pectoral fin is the first to appear and the last to complete its development. The caudal fin completes development first, followed in order by the dorsal, anal, and pelvic fins. By about 8 mm. SL the adult complement of fin rays is present in the caudal, dorsal, and anal fins (fig. 2).

Pectoral Fin

The pectoral fin is present on my smallest larva (1.72 mm. SL) and is not fully developed on my largest specimen (14.5 mm. SL). Initially it is large and rayless.

Caudal Fin

The fully formed caudal fin has 17 principal fin rays associated with the four hypural elements. The dorsal and ventralmost caudal fin rays are simple; the remaining rays are branched. Principal caudal fin rays are separable into two groups. The nine upper rays are associated with the two superior hypurals and the eight lower rays with the two inferior hypurals (4–5–4–4). No caudal fin rays are associated with neural and haemal spines of the penultimate vertebra. A ventral thickening near the posterior end of the notochord is seen on specimens about 3.5 mm. SL. This thickened tissue develops into the two median hypural plates and their associated caudal fin rays. The first four caudal fin rays to develop are seen first on a 5.44 mm. SL specimen and appear simultaneously (fig. 2). They develop at an oblique angle to the notochord and are divided into two groups, upper and lower. This division separates the caudal fin into superior and inferior components. By about 8 mm. SL the notochord has turned dorsally, the hypurals and caudal fin rays are arranged parallel to the axis of the body, and all principal caudal fin rays are developed (fig. 2), but the caudal osteology is not fully developed until a larger size.

Dorsal Fin

Dorsal fin ray development is an important taxonomic character in larval flatfish. These fin rays begin to develop in a thickened area above the nape on specimens of about 2 mm. SL. My smallest specimen with dorsal fin rays (three elongate rays) is 2.08 mm. SL (see app. table 1). The origin of the dorsal fin base moves anteriorly on the larvae until the fin base is over the eye; at this time dorsal fin rays begin developing posterior to the nape. All elongate dorsal fin rays develop first. The origin of the dorsal fin continues to shift anteriorly until it becomes attached to the ethmoid region of the cranium ahead of the eye. The first three fin rays must develop simultaneously; all but three of the specimens between 2 and 3 mm. SL have three or four fin rays (one with two, and two with five). The number of fin rays on all but four specimens between 3 and 5 mm. SL does not exceed 10 (one with 11 and three with 14), and most of the rays are elongate. The number of fin rays increases rapidly between 5 and 8 mm. SL; at 8 mm. SL the adult complement of 78 to 87 fin rays is present (fig. 2). Three of my 19 larval specimens exceeding 8 mm. SL had 77 fin rays, and one had 76.

Anal Fin

Fifteen anal fin rays were present on a 5.9 mm. SL specimen; none were discernible on smaller specimens (fig. 2; app. table 1). The number of fin rays increased rapidly, as in the dorsal fin, and the adult complement of 59 to 67 fin rays was developed by about 8 mm. SL (fig. 2). Four of 19 specimens exceeding 8 mm. SL had fin ray counts of 58, three had fewer than 58, and the others had counts between 59 and 67 (see app. table 1).

Pelvic Fins

Pelvic fin bases develop early. The left-side fin base and its three elongate anterior fin rays develop earlier than the right-side fin base. The left-side fin base is first noted on specimens of about

2.5 mm. SL as a thickening on the ventral edge of the body immediately anterior to the gut, but the right-side base does not appear until about 3.5 mm. SL. My smallest specimen with pelvic fin rays (left side, and elongate rays) was 3.0 mm. SL. The first right-side fin ray is seen on a 5.3 mm. SL specimen. The three elongate pelvic fin rays on the left side develop simultaneously. They are present on all specimens but two (one with a single fin ray and one with two fin rays). The fourth left fin ray develops at about 5 mm. SL, and the fifth and sixth rays by about 10 mm. SL. Each fully developed pelvic fin has six fin rays. The three elongate fin rays of the left side are thickened and heavier than the other pelvic fin rays and extend posteriorly to about the caudal peduncle; they are often broken. None of the other pelvic fin rays is elongate. The origins of the pelvic fin base are equidistant behind the cleithrum.

LARVAL SPINATION

A single sphenotic spine and a series of preopercular spines (figs. 3–7) persist throughout the size series of my larval specimens (1.72–14.51 mm. SL). These spines are smaller but similar in position and shape to those reported for *Syacium* by Kyle (1913) and Aboussouan (1968). The sphenotic spine becomes relatively smaller as the larvae grow. The spine is surrounded by concentric rings that are first noted on specimens of about 4.6 mm. SL. Four to six small sharp spines are present on the preopercular margin; two or three of these are on the ventral edge, a larger single spine is at the angle, and two more small spines are on the posterior edge. The large spine at the angle of the preopercle thickens, and a spur develops on the upper posterior edge of the spine on larger larvae. These spines do not alter position or shape but become relatively smaller with increasing size of the larvae. The sphenotic and preopercular spines can be traced through the developmental series and are important in identifying this group of larvae (figs. 3–7).

PIGMENTATION

Pigment on all of the *Theodore N. Gill* material is faded, but pigment patterns are readily seen on the fresh *Oregon* material. In my sample, pigment is first seen on a 2.8 mm. SL specimen—a large melanophore over the base of each sphenotic spine, and another melanophore on the gular region between the posterior end of the lower jaws and the tip of the cleithrum. The dorsal portion of the swim bladder and the dorsal loop of the gut are heavily pigmented. On a 3.2 mm. SL specimen the melanophores at the bases of the sphenotic spines have faded, but those on the gular region and along the dorsal aspect of the gut remain. Three clusters of melanophores are present on the dorsal edge, and two are on the ventral edge of the body. The anteriormost is on the dorsal edge of the body over the pectoral fin base (there is no corresponding ventral cluster of melanophores). The other two dorsal clusters of melanophores have corresponding ventral clusters. The middle spots are immediately behind the gut region, at about the midpoint of the body (TL), and the posterior spots are slightly anterior to the caudal peduncle (fig. 4). A series of small melanophores can be seen on the ventral edge of the gut between the vent and the anterior portion of the gut cavity. Pigmentation is essentially the same on specimens up to about 4 mm. SL, but the number of melanophores increases. Specimens between 4 and 5 mm. SL have a large melanophore on each opercle behind the eye and another on the median line at the origin of the pelvic fin base. The dorsal portion of the gut has two areas of dark pigment; the anteriormost is on the upper half of the swim bladder and the other is above the loop of the intestine.

At about 5 mm. SL the melanophore on the gular region has disappeared, but additional clusters of melanophores have appeared, one dorsal and one ventral, between the middle and posteriormost cluster but nearer the posteriormost cluster. The two new clusters are of equal size and are smaller than those nearest to them. The remaining pigment is similar to that seen on the smaller larvae. Shortly after appearance of the third ventral pigment cluster the posteriormost ventral cluster increases in length and becomes longer than its corresponding dorsal area.

By 7 mm. SL a fifth dorsal cluster has appeared between the first two clusters. Two pigment clusters have developed along the lateral septum, corresponding in position with the two posterior dorsal and ventral clusters. Pigment is present over the entire swim bladder on the left side and absent on the right side. Pigmentation remains essentially the same through the rest of the larval

series in my sample, except for darkening and the appearance of pigment at the distal edge of the caudal peduncle, in the branchial chambers, and around the urohyal (figs. 5 and 6).

MIGRATION OF THE EYE

Specimens of 7 mm. SL are symmetrical; the right eye has not begun to migrate (fig. 5). The dorsal fin continues its development anteriorly, and its origin is over the anterior edge of the eye. The supraorbital bars on the cranium have not begun to become modified.

By about 8 mm. SL the right eye has moved only slightly; the origin of the dorsal is above and posterior to the ethmoid region of the cranium and the origin of the fin base remains unattached. Tissue between the ventral edge of the anterior portion of the dorsal fin and the frontal region of the cranium is becoming thin, and the supraorbital bars have begun to shift onto the ocular sides as an accompanying depression begins to form above the left eye.

By 10.5 mm. SL the right eye has migrated dorsoanteriorly but its upper edge is not yet level with the supraorbital bars; the origin of the dorsal is attached to the ethmoid region of the cranium and its point of attachment has shifted onto the right side of the head, over the nostrils. The right side is the blind side in the adult. The area of thin tissue between the dorsal fin and the supraorbital bars is wider. The supraorbital bars continue their shift to the left side, and the depression of the cranium above the left eye is larger.

On a 14 mm. SL specimen the upper edge of the right side eye is visible through the thin tissue below the dorsal fin (fig. 7). The shifting of the supraorbital bars has created a large depression over the left eye. The origin of the dorsal fin remains attached. The right eye has not yet begun to move through the head onto the left side. In larger specimens the eye will move through the head in the area between the dorsal fin and the depression created by the shift of the supraorbital bars.

SEQUENCE OF OSSIFICATION

I cleared and stained several specimens to determine the sequence of ossification. The degree of ossification can be assessed by the intensity of the stain (alizarin red S) absorbed by the bone. In this discussion I consider any bone that absorbed stain to be ossified.

On a 1.7 mm. SL specimen only the cleithrum, the distal edges of the preopercle and preopercular spines, and the sphenotic spine and its base showed any ossification.

By 3 mm. SL some ossification is seen in the cranial cap, lower jaw, premaxillary, and the four elongate dorsal fin rays. By 3.5 mm. SL the three elongate pelvic fin rays, the maxillary, four branchiostegal rays, and six elongate dorsal fin rays are ossified. The palatine and parasphenoid are stained and extend from the symphysis of the upper jaw to the cleithrum; these bones will form part of the floor of the neurocranium. At this size all stained areas are in the head and pelvic fin region. Six canine teeth are present in the lower and four in the upper jaw, but none are stained. A slight thickening on the ventral edge of the posterior part of the notochord is the rudimentary hypural, and it is only slightly ossified, if at all.

Ossification is still restricted to the head and pelvic fin base region at 4.1 mm. SL. All seven branchiostegal rays, the urohyal, and the preopercle and opercle in the opercular series are now ossified. The vertebrae and neural and haemal spines have not begun to ossify. Ossification at 4.9 mm. SL is essentially similar to that of the 4.1 mm. SL specimen; again the anterior neural and haemal spines are visible but are not stained. They are not attached to the vertebrae and appear as thin lines between the vertebrae and the dorsal and anal fin rays.

At 5.5 mm. SL the right pelvic fin base, three or four caudal fin rays (but not the hypural elements), the dorsal aspect of the subopercle, and some vertebrae and associated neural and haemal spines have begun to ossify. The 16 anterior neural spines and the anterior seven haemal spines, and the dorsal rim and sides of the neural arch on the second, third, and fourth vertebrae are lightly stained. The first vertebra and its neural spine are not stained. The occipital region of the neurocranium and the scapula have begun to ossify.

The areas of ossification, as determined by absorption of alizarin red S stain, are larger and the color is more intense at 6.4 mm. SL than on smaller specimens. At this size the notochord is upturned and two hypural elements are differentiated. Ten caudal fin rays are stained, and five are associated

with each hypural element. The notochord has neural and haemal spines on nearly its full length. Most neural arches, but only the anterior haemal arches, are stained. Pterygiophores of the anterior elongate dorsal fin rays are developing. About 40 dorsal and 24 anal fin rays are stained. The interopercle has begun to ossify, and all four opercular elements show some ossification. The supraorbital bars are stained and are visible as anterior extensions of the neurocranium. The auditory region of the neurocranium is partially stained, and the post cleithrum is ossifying.

By 10 mm. SL ossification has progressed considerably, and many bones in the head, vertebrae, and caudal fin can be recognized. At about 10 mm. SL ossification is noted in the hypural elements, the basal part of the urostyle, and the parapophysis of the last abdominal (precaudal) vertebra. The dorsal aspects of the posterior 14 and the anteriormost 3 or 4 vertebrae are lightly stained; the remaining vertebrae are not stained. All neural and haemal spines and arches are ossified except for those on the penultimate vertebra. There are 16 caudal fin rays: Four are associated with each of the two inferior hypurals, the superior hypurals are indistinguishable. Four to six pelvic fin rays have developed on each fin base, and the pelvic bone is beginning to ossify. The supraorbital bars extend forward; their anterior edge is above the nostril. The entopterygoid, which is immediately above the pterygoid, is lightly stained. Bones of the lower jaw suspension can be identified; the quadrate, hyomandibular, and pterygoid are lightly stained. The supracleithrum and posttemporal region of the cranium can be distinguished. The upper jaw now has about 10 teeth and the lower 16; those near the symphysis are relatively small and close together. A "cartilaginous" bar extends posteriorly along the ventral median edge of the gut from the distal edge of the pelvic fin base to below the liver. The anterior ventral edge of the urohyal is hooked and pointed forward.

Ossification has changed little at about 14 mm. SL except on the vertebrae (fig. 7). The first abdominal (precaudal) vertebra is completely ossified, and the dorsal aspect and one-third to one-fourth of the lateral surfaces of the other abdominal vertebrae are ossified. The parapophyses of the last four abdominal vertebrae are also ossified, but no ribs are seen. Ossification of the parapophyses begins with the last abdominal vertebra and proceeds anteriorly to the fifth vertebra, the last one with a parapophyses. The first through the 18th caudal vertebrae show the same degree of ossification; posteriorly they become progressively more ossified until ossification is complete on the last four vertebrae. Interneurals and interhaemals are developing between the fifth and 10th neural and haemal spines. The enlarged pterygiophore, which is associated with the first 10 to 12 anal fin rays, is now lightly stained.

My largest larva (14.5 mm. SL) is stained and shows essentially the same degree of ossification as the 14 mm. SL specimen. The vertebral column, pterygiophores of the dorsal and anal fins, and all bones of the neurocranium and branchiocranium are not completely ossified. The supraorbital bars extend forward onto the ethmoid region and form the frontals. The right side supraorbital bar appears to be partially reabsorbed as suggested by its upturned anterior medial edge in the sphenotic region and its position and thinness. The left supraorbital bar has moved closer to the left eye. After movement of the supraorbital bar is complete the left side bar and part of the right side bar form the interorbital bar, and the remaining part of the right supraorbital bar is reabsorbed. At a larger size the right eye will move under the dorsal fin and stop at the interorbital bar. The sphenotic and preopercular spines are still present at 14.5 mm. SL but will eventually be reabsorbed or broken off and leave the surface smooth.

SPAWNING AND DISTRIBUTION

Larvae were collected between Jupiter Inlet, Fla., and Cape Hatteras, N.C. (fig. 1) in surface waters over depths of 11 to 2,510 m. (6–1,372 fath.); 21 stations were in depths greater than 183 m. (100 fath.) and 54 stations in depths less than 183 m.

Specimens were collected primarily north of lat. 30° N. (70 collecting sites were north and only 5 were south of lat. 30° N.). Sixty-nine larvae were taken at 35 stations occupied at night, and 102 were taken at 38 stations occupied during the day. No larvae were collected between November and April; one larva was taken in April and one in November; and the rest in May to October (fig. 15).

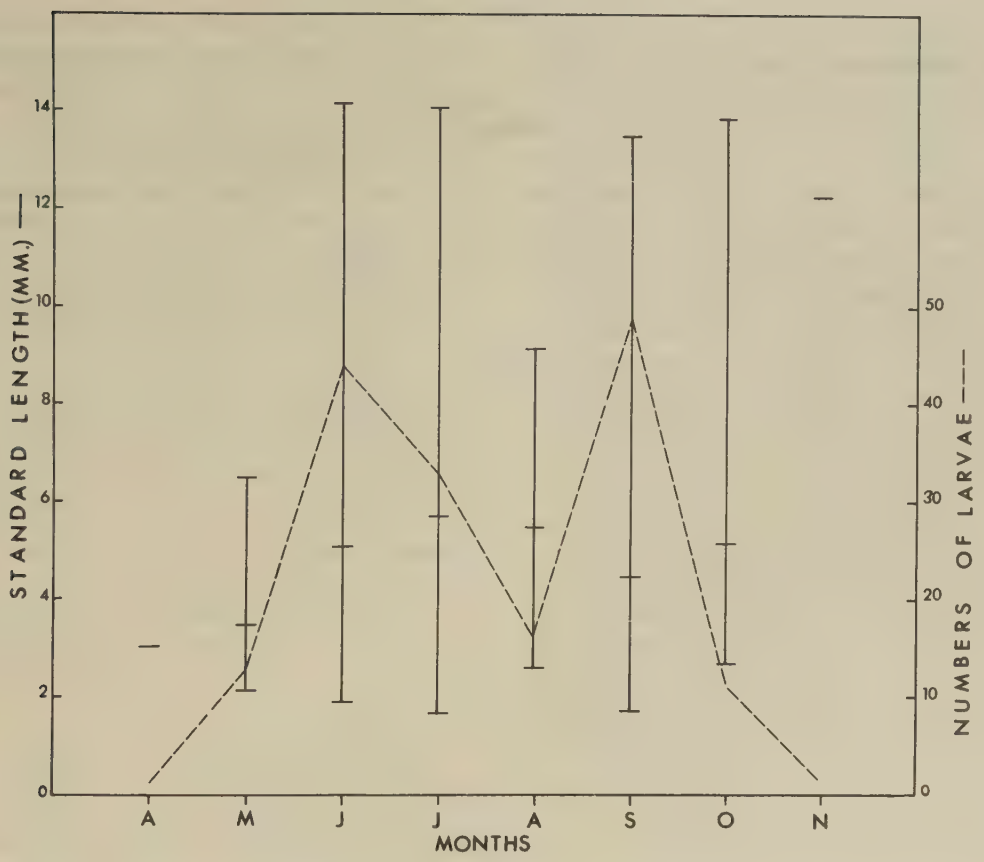

FIGURE 15.—Size range and mean size of larvae collected from April to November. Frequency of larvae per month also shown.

The *Theodore N. Gill* data by themselves show a single spawning peak in September, but the combined *Theodore N. Gill* and *Oregon* data suggest a bimodal spawning period with peaks in June and September. The first larvae appear in April, and numbers increase sharply until June; after September the numbers decrease sharply to November. Larvae 2.6 mm. SL and smaller were collected each month from May through October. I estimate that hatching size is about 1.5 mm. SL; therefore, spawning must occur throughout this period. The mean size of the larvae increases through July and then decreases in September. This size decrease is correlated with a spawning peak (fig. 15). My samples contain no larvae exceeding 9 mm. SL until the last week in June, but larvae of this size are present in succeeding months through November (fig. 15). These size data support the supposition that spawning begins in the spring.

I have not seen spawning fish, but I have examined gonads from *C. fimbriata* taken throughout the year off Cape Kennedy, Fla. None of the gonads were ripe, but the ovaries enlarged progressively from spring to fall. In the winter the ovaries are very thin and flat. My examination of gonad development indicates a spawning period from early spring to late fall—again supporting conclusions based on the samples of larvae.

I tried to determine where *C. fimbriata* spawns by analyzing the collection data for 28 smaller larvae (1.7 mm.–3.0 mm. SL). These specimens were collected at 17 stations on *Theodore N. Gill* and *Oregon* cruises. Ten of the 17 stations were occupied during daylight; of these six were in 46 m. (25 fath.) or less. Three of the seven nighttime stations were in depths of 46 m. (25 fath.) or less. Small larvae were collected from May through October from Florida to North Carolina. Because hatching size is estimated to be about 1.5 mm. SL, specimens less than about 2.0 mm. SL must have

been collected close to the spawning area, but this view may be erroneous because the time required for hatching of the eggs is unknown. Six specimens (1.72–2.01 mm. SL) were collected from five stations, at the surface in 22 to 450 m. (12–246 fath.) during both day and night. These small larvae were caught from July to September from Georgia to North Carolina. It appears that *C. fimbriata* spawns from April to October throughout the entire collection area on the Continental Shelf and that most spawning is in waters of 46 m. (25 fath.) or less. Delineation of the spawning area of *C. fimbriata* must await the collection or observation of spawning fish.

ACKNOWLEDGMENT

Elbert H. Ahlstrom of the BCF Fishery-Oceanography Center, La Jolla, Calif., reviewed the manuscript and made many helpful suggestions. Assistance by various staff members of the laboratory included review of the manuscript, preparation of figures 3 through 7, and preparation of stained material.

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APPENDIX

TABLE 1.—*Selected measurements and counts of larval* Cyclopsetta fimbriata

Measurements													Counts	
Standard length	Head length (HL)		Body depth (BD)		Eye diameter (ED)		Upper jaw length (UJL)		Lower jaw length (LJL)		Snout length (SN)		Pelvic fin origin to tip of cleithrum [1] *blind-side* ocular-side	Dorsal fin rays	Anal fin rays
Mm.	*Mm.*	*HL/SL*	*Mm.*	*BD/SL*	*Mm.*	*ED/HL*	*Mm.*	*UJL/HL*	*Mm.*	*LJL/HL*	*Mm.*	*SN/HL*	*Percent*	*Number*	*Number*
1.72	0.54	32			0.20	37									
1.76			0.42	24	.20	45					0.07	16			
1.79	.59	33	.49	27	.22	37					.10	17			
1.89															
2.01	.64	32	.64	32	.24	37					.07	11			
2.01	.59	29			.27	48									
2.08	.76	37			.29	38					.15	20		3	
2.33	.69	30			.29	42					.12	17		4	
2.33	.74	32			.29	39					.12	16		4	
2.45	.74	30			.29	39					.12	16		4	
2.60	.86	33			.34	40								4	
2.60	.76	29			.29	38					.07	9		3	
2.64	.78	30	.76	29	.29	37	0.27	35	0.42	54	.12	15		3	
2.72	.81	30	.81	30	.29	36	.27	33	.39	48	.12	15		3	
2.72	.78	29	.81	30	.27	35			.34	44	.10	13		3	
2.72	.73	27	.73	27	.32	44			.37	51				4	
2.72	.93	34	.96	35					.42	45				3	
2.75	.76	28	.64	23	.29	38					.10	13		2	
2.79	.86	31	.86	31	.29	34					.17	20		4	
2.83	.86	30	.91	32	.34	40	.32	37	.44	51	.15	17		3	
2.87	.88	31	.98	34	.34	39	.32	36	.47	53	.15	17	83	5	
2.91														4	
2.91	.83	29	.86	30	.32	39	.27	33	.39	47	.17	21		3	
2.91	.78	27	.71	24	.29	37	.24	31	.42	54	.12	15		3	
2.91	.93	32	.98	34	.37	40			.47	51	.17	18	120	5	
2.91	.88	30	.83	29	.34	39	.37	42	.44	50	.12	14	85	3	
2.95	.86	29	.86	29	.34	40			.37	43	.15	17	83	4	
2.95	.83	28			.32	39	.24	29	.39	47	.12	14		3	
3.03	.83	27	.78	26	.34	41	.27	33	.37	45	.12	14		3	
3.03	.98	32	1.03	34	.37	38			.42	43	.12	12		4	
3.10														4	
3.10					.44	37	.49	42	.61	52	.34	29		6	
3.10	.93	30			.32	34	.34	37	.44	47	.24	26	100	4	
3.10	.91	29	.91	29	.37	41			.37	41	.12	13	100	4	
3.10	.98	32	1.03	33	.39	40	.34	35	.49	50	.17	17	100		
3.14	1.03	34	1.23	39	.49	48	.34	33	.56	54	.22	21		7	
3.14	.98	31	1.03	33	.37	38	.32	33	.42	43	.22	22		5	
3.22	1.00	31	1.25	39	.39	39			.51	51	.24	24		5	
3.22	1.05	33	1.10	34	.37	35	.29	28	.49	47				5	
3.30	.91	28			.32	35	.32	35	.47	52	.20	22		4	
3.30	1.03	31	1.10	33	.39	38					.15	15	100	5	

See footnote at end of table.

TABLE 1.—*Selected measurements and counts of larval* Cyclopsetta fimbriata—Continued

Measurements													Counts	
Standard length	Head length (HL)		Body depth (BD)		Eye diameter (ED)		Upper jaw length (UJL)		Lower jaw length (LJL)		Snout length (SN)		Pelvic fin origin to tip of cleithrum [1] *blind-side* ocular-side	Dorsal fin rays	Anal fin rays
Mm.	*Mm.*	*HL SL*	*Mm.*	*BD SL*	*Mm.*	*ED HL*	*Mm.*	*UJL HL*	*Mm.*	*LJL HL*	*Mm.*	*SN HL*	*Percent*	*Number*	*Number*
3.34	1.05	31	1.10	33	0.42	40	0.39	37	0.61	58	0.17	16	100	5	
3.35	.98	29	.98	29	.34	35	.32	33	.42	43	.17	17		4	
3.38	.98	29	1.13	33	.37	38			.49	50	.20	20	71	6	
3.41	1.03	30	.98	29	.37	36					.20	19	88	5	
3.42	1.25	37	1.45	42	.42	34			.61	49	.22	18		6	
3.48	1.22	35	1.30	37	.37	30	.42	34	.54	44	.34	28	100	6	
3.48	1.27	37	1.22	35									71	6	
3.48	1.30	37	1.30	37	.37	28	.44	34	.54	42	.29	22	75	8	
3.48	1.00	29	1.15	33									88	4	
3.49	1.36	39	1.35	39	.39	29	.39	29	.51	37	.29	21	125	7	
3.49	1.13	32	1.27	36	.37	33	.42	37	.54	48			83	6	
3.54	1.37	39	1.67	47	.39	28	.59	43	.69	50	.37	27	83	7	
3.54	1.30	37	1.35	38	.39	30	.49	38	.56	43	.27	21		7	
3.54	1.15	33	1.25	35	.42	37	.34	30	.51	44	.24	21	80	9	
3.54	1.27	36	1.47	42	.44	35	.49	39	.59	46	.27	21		7	
3.61	1.18	33	1.30	36	.42	36	.37	31	.54	46	.27	23		6	
3.61	1.13	31	1.22	34	.39	35			.49	43	.22	19	88	4	
3.67	1.20	33												6	
3.67	1.47	40	1.47	40	.39	27	.56	38	.64	44	.34	23	77	8	
3.73	1.32	35	1.64	44	.47	36	.51	39	.66	50	.34	26		5	
3.76	1.32	35			.39	30					.32	24		7	
3.80	1.15	30	1.54	41	.44	38	.51	44	.66	57	.29	25		7	
3.80	1.25	33	1.62	43	.42	34	.51	41	.64	51	.32	26		7	
3.88	1.15	30	1.15	30	.44	38			.59	51	.29	25	113	6	
3.88	1.30	34	1.35	35	.42	32					.24	18		6	
3.88	1.18	30	1.40	36	.39	33					.24	20	71	7	
4.05	1.42	35	1.64	40	.47	33	.54	38	.69	49	.32	23	88	7	
4.05	1.32	33	1.59	39	.49	37			.66	50	.27	20			
4.05	1.42	35	1.49	37	.47	33	.44	31	.64	45	.34	24		7	
4.11	1.40	34	1.46	36			.61	44	.78	56	.42	30	82		
4.11	1.40	34	1.54	37	.44	31	.54	39	.86	61	.32	23		7	
4.11	1.30	32	1.35	33	.47	36	.44	34	.56	43	.27	21	77	7	
4.24	1.27	30			.44	35					.20	16		6	
4.24	1.35	32			.39	29					.32	24		6	
4.24	1.27	30	1.59	38	.44	35					.20	16	80	8	
4.24	1.37	32	1.67	39	.49	36			.64	47	.30	22		8	
4.30	1.30	30	1.42	33	.42	32	.47	36	.64	49	.32	25	71	6	
4.37	1.45	33	1.72	39	.47	32	.54	37	.66	46	.32	22	80	9+	
4.43	1.30	29			.42	32								7	
4.43	1.32	30	1.57	34	.47	36	.37	28	.61	46	.32	24	68	6	
4.43	1.35	30	1.54	35	.39	29	.39	29	.56	41	.20	15	80	7+	
4.43	1.59	36	2.08	47										14	
4.49	1.42	32			.47	33	.49	35	.66	46	.22	15		7	
4.56	1.45	32	1.64	36	.51	35							75	8	
4.62	1.45	31	1.59	34	.44	30	.47	32	.64	44	.34	23	77	7	
4.62	1.52	33	2.11	46	.54	36	.56	37	.73	48	.39	26		14	
4.62	1.59	34	1.89	41	.47	30			.73	54	.37	23		9	
4.62	1.47	32	1.76	38	.49	33			.69	47				8	
4.75	1.47	31	1.86	39	.54	37			.69	47	.27	18	77	8	
4.75	1.54	32	1.57	33	.47	31	.42	27	.56	36	.29	19	100	7	
4.75	1.42	30	1.59	33	.47	33	.39	27	.59	42	.22	15	88	6	
4.81	1.52	32	1.72	36	.49	32	.51	34	.71	47	.32	21	77	3	
4.81	1.79	37	1.98	41	.54	30	.61	34	.78	44	.39	22		14	
4.87	1.59	33	1.79	37	.49	31	.59	37	.69	43	.37	23	77	10	
4.87	1.47	30			.49	33					.32	22		8	
4.94	1.72	35	2.25	46	.56	33	.69	40	.81	47	.39	23			
4.94	1.52	31	1.72	35	.51	34	.51	34	.71	47	.24	16	125	8	
4.94	1.72	35	1.81	37	.49	28	.49	28	.64	37	.34	20	77	10	
4.94	1.52	31	1.64	33	.49	32	.49	32	.61	40	.32	21	85	11	
5.00	1.64	33	1.91	38										7	
5.06	1.67	33	1.96	39	.49	29	.51	31	.76	46	.49	29		10	
5.06	1.54	30	1.67	33	.47	31	.49	32	.64	42	.32	21		7	
5.06	1.59	31	1.72	34	.51	32	.51	32	.69	43	.32	20	80	8	
5.06	1.49	29	1.81	36	.49	33	.51	34	.66	44	.27	19		9	
5.19	1.64	32	1.96	38	.47	29	.61	37	.76	46	.39	24		12	
5.32	1.59	30	1.86	35	.49	31	.51	32	.66	42	.37	23		9	
5.32	1.62	30	1.74	33	.49	30	.54	33	.71	44	.34	21		8	
5.32	1.76	33	2.16	41	.54	31	.64	36	.81	46	.39	22	83	20	
5.44	1.81	34	2.33	43	.56	30	.66	36	.91	49	.47	26	85		
5.44	1.81	33	2.08	38	.54	30	.51	28	.69	38	.37	20	71	16	
5.44	1.72	32	1.94	37	.51	30	.66	38	.78	45	.44	26	77	16	
5.57	1.91	34	2.16	39	.54	28	.61	32	.78	41	.39	20	85	45	
5.89	2.08	35	2.45	42	.56	27	.69	33	.86	41	.47	23	83	20	15
6.01	1.89	31	2.13	35	.56	30	.69	37	.86	46	.56	30	75	50	25
6.01	1.89	31	2.13	35	.56	30	.61	32	.81	43	.51	27	85	53	35
6.08	1.84	30			.61	33	.52	28	.74	40	.37	20	92		
6.14	1.96	32	2.20	36	.49	25	.54	28	.74	38	.49	25	77	55	33
6.29	2.08	33	2.20	35	.49	24	.73	35	.81	39	.42	20	83	74	42
6.39	2.08	33	2.45	38	.59	28			.86	41	.49	24		56	38
6.39	2.20	34	2.87	45	.59	27	.73	33	.98	45	.56	25	81	68	42
6.50	2.07	32	2.60	40	.56	27	.64	31	.88	43	.47	23	88	55	
6.50	1.94	30	2.23	34	.56	29	.61	31	.78	40	.42	22			
6.70	2.20	33	2.35	35	.54	25	.64	29	.83	38	.44	20	68	58	35

See footnote at end of table.

TABLE 1.—*Selected measurements and counts of larval* Cyclopsetta fimbriata—Continued

Measurements													Counts	
Standard length	Head length (HL)		Body depth (BD)		Eye diameter (ED)		Upper jaw length (UJL)		Lower jaw length (LJL)		Snout length (SN)		Pelvic fin origin to tip of cleithrum [1] *blind-side* ocular-side	Dorsal fin rays	Anal fin rays
Mm.	*Mm.*	*HL SL*	*Mm.*	*BD SL*	*Mm.*	*ED HL*	*Mm.*	*UJL HL*	*Mm.*	*LJL HL*	*Mm.*	*SN HL*	*Percent*	*Number*	*Number*
6.70	2.08	31	2.72	41	0.64	31	----------		0.78	38	0.42	20	69	64	44
6.80	2.08	31	2.45	36	.49	24	----------		.86	41	.42	20	100	----------	----------
6.91	2.16	31	2.45	35	.56	26	.71	33	.93	43	.42	19	77	----------	39
7.01	2.20	31	2.72	39	.56	25	.74	34	.93	42	.56	25	83	73	50
7.01	2.28	33	2.83	40	.61	27	.81	36	.98	43	.49	21	78	66	46
7.53	2.38	32	2.83	38	.69	29	.81	34	1.03	43	.56	24	75	----------	----------
7.63	2.38	31	3.03	40	.66	28	----------		1.03	43	.59	25	84	72	50
8.04	2.56	32	3.22	40	.69	27	.93	36	1.10	43	.61	24	88	79	62
8.04	2.64	33	3.14	39	.74	28	.91	34	1.10	42	.59	22	83	----------	----------
8.25	2.83	34	3.49	42	.74	26	1.00	35	1.22	43	.74	26	88	----------	----------
8.76	2.91	33	3.69	42	.71	24	1.00	34	1.15	40	.66	23	71	79	56
9.18	2.79	30	3.30	36	.69	25	----------		----------		.69	25	74	81	57
9.38	3.38	36	4.30	46	.71	21	1.00	30	1.35	40	.86	25	71	79	60
9.38	2.95	31	3.80	41	.74	25	1.03	35	1.22	41	.74	25	78	82	63
9.59	3.49	36	4.24	44	.69	20	1.00	29	1.30	37	.81	23	92	77	54
9.79	2.91	30	3.61	37	.71	24	.91	31	1.18	41	.74	25	65	76	60
10.21	3.03	30	4.11	40	.66	22	.98	32	1.15	38	.73	24	71	81	61
10.31	3.65	35	4.62	45	.81	22	----------		1.52	42	.88	24	69	77	58
10.31	3.10	30	4.24	41	.71	23	1.10	36	1.35	44	.73	24	61	78	60
10.31	3.18	31	4.11	40	.74	23	1.10	35	1.32	42	.74	23	74	79	59
11.08	3.57	32	4.43	40	.78	22	1.15	32	1.42	40	.91	25	100	82	62
12.06	3.80	32	4.56	38	.86	23	.98	26	1.35	36	.86	23	79	77	58
12.23	3.99	33	4.89	40	.91	23	1.32	33	1.71	43	.91	23	78	82	58
13.20	4.49	34	5.38	41	.86	19	1.42	32	1.84	41	1.18	26	73	82	61
13.53	4.18	31	5.25	39	.93	22	1.35	32	1.72	41	.98	22	82	84	61
13.86	4.30	31	----------	----------	.91	21	1.25	29	1.71	40	.98	23	65	----------	----------
14.02	4.62	33	5.51	39	.98	21	1.59	34	1.98	43	1.05	23	92	80	60
14.18	4.75	33	6.01	42	.93	20	1.49	31	2.03	43	1.22	26	73	83	61
14.51	4.75	33	5.87	40	1.22	26	1.40	29	1.84	39	1.10	23	78	80	58

[1] Distance between the origin of the right side pelvic fin base and the tip of the cleithrum divided by the distance between the origin of the left side pelvic fin base and the tip of the cleithrum.

TABLE 2.—*Average values for selected measurements and counts (½-mm. size intervals to 5.0 mm. SL; 1-mm. intervals for larger sizes); all specimens in a given size series were not necessarily used to compute the mean*

Measurements															Counts	
Standard length		Specimens	Head length (HL)		Body depth (BD)		Eye diameter (ED)		Upper jaw length (UJL)		Lower jaw length (LJL)		Snout length (SN)		Pelvic fin origin to tip of cleithrum [1] *blind-side* ocular-side	Dorsal fin rays	Anal fin rays
Range	*Mean*		*Mean*	*HL SL*	*Mean*	*BD SL*	*Mean*	*ED HL*	*Mean*	*UJL HL*	*Mean*	*LJL HL*	*Mean*	*SN HL*			
Mm.	*Mm.*	*Number*	*Mm.*		*Mm.*		*Mm.*		*Mm.*		*Mm.*		*Mm.*		*Percent*	*Number*	*Number*
1.50–1.99	1.79	4	0.50	28	0.52	29	0.21	40	----------		----------		0.09	17	----------	----------	----------
2.00–2.49	2.20	6	.69	32	.64	32	.28	40	----------		----------		.12	16	----------	3.8	----------
2.50–2.99	2.80	18	.83	30	.84	30	.32	38	0.28	33	0.41	49	.13	16	93	3.4	----------
3.00–3.49	3.28	23	1.06	32	1.12	34	.38	37	.37	35	.50	47	.21	20	92	5.2	----------
3.50–3.99	3.68	15	1.25	34	1.42	39	.42	34	.49	38	.60	48	.29	23	85	6.6	----------
4.00–4.49	4.25	17	1.37	32	1.59	37	.44	33	.48	35	.66	48	.29	21	78	7.5	----------
4.50–4.99	4.78	16	1.55	32	1.79	38	.50	32	.52	33	.68	44	.33	21	86	12.1	----------
5.00–5.99	5.30	16	1.70	32	1.98	38	.51	30	.57	33	.75	44	.39	23	81	14.3	15.0
6.00–6.99	6.42	13	2.04	32	2.40	37	.56	28	.64	32	.84	41	.46	23	81	54.8	37.0
7.00–7.99	7.30	4	2.31	32	2.85	39	.63	27	.79	35	.99	43	.55	24	80	70.3	48.6
8.00–8.99	8.27	4	2.74	33	3.38	41	.72	26	.96	35	1.14	42	.65	24	82	79.0	59.0
9.00–9.99	9.46	5	3.10	33	3.85	41	.71	23	.98	31	1.26	40	.77	25	76	79.0	58.8
10.00–10.99	10.28	4	3.24	32	4.27	42	.73	22	1.06	34	1.34	42	.77	24	69	78.8	59.5
11.00–11.99	11.08	1	3.57	32	4.43	40	.78	22	1.15	32	1.42	40	.91	25	100	82.0	62.0
12.00–12.99	12.14	2	3.90	32	4.72	39	.88	23	1.15	30	1.53	40	.88	23	78	79.5	58.0
13.00–13.99	13.53	3	4.32	32	5.32	40	.90	21	1.34	31	1.76	41	1.05	24	73	83.0	61.0
14.00–14.99	14.24	3	4.71	33	5.80	40	1.04	22	1.49	31	1.95	42	1.12	24	81	81.0	59.7

[1] Distance between the origin of the right side pelvic fin base and the tip of the cleithrum divided by the distance between the origin of the left side pelvic fin base and the tip of the cleithrum.

CONTROL OF OYSTER DRILLS, EUPLEURA CAUDATA *AND* UROSALPINX CINEREA, *WITH THE CHEMICAL POLYSTREAM*

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ABSTRACT

Five experimental and 10 commercial treatments of oyster beds in four States were made with Polystream. On a typical bed, where water currents were less than 2.7 km. per hour, Polystream killed about 85 percent of the thick-lipped drill, *Eupleura caudata*, and 66 percent of the Atlantic oyster drill, *Urosalpinx cinerea*. A significantly higher percentage of oyster drills was killed by treatments made in late April and early May rather than later in the summer. Oyster drills that survived did not feed for several months. The number of drills remained low for at least 2 years. Polystream treatments killed only small percentages of fish, small clams, *Mercenaria mercenaria*, crabs, and other invertebrates. After a treatment, oysters, *Crassostrea virginica*, clams, and other organisms had small residues of Polystream in their tissues but gradually lost these residues. Growth of oysters was normal on treated beds.

Boring gastropods, known as oyster drills, and starfish, *Asterias forbesi*, are the most serious predators of oysters in Long Island Sound. The drills prey heavily on oysters, *Crassostrea virginica*, along the entire Atlantic Coast, from Canada to Florida, and in certain areas of the Pacific Coast. Where they are extremely numerous, oyster drills destroy nearly all oysters on commercial beds. In Long Island Sound, however, drills usually reduce the number of oysters to such a level that most beds are of marginal value commercially.

This article summarizes laboratory and field experiments made during the development of a control method of oyster drills for use on commercial oyster beds in southern New England and New York; it includes the results of 15 treatments during 1961–67.

HISTORY OF DEVELOPMENT OF METHOD

All early phases of work on the development of a method of control of oyster drills by use of Polystream, including the initial testing of chemicals, was done by the biological laboratory at Milford, Conn. Field tests and commercial applications of Polystream were made under the inspection of the author in the States of Connecticut, New York, Rhode Island, and Massachusetts. Additional independent laboratory and field studies were later made in Virginia.

EXPERIMENTAL WORK AT MILFORD

In 1946, the Fish and Wildlife Service biological laboratory, Milford, Conn., began a program of screening organic chemicals with the goal of eventually developing a method to control oyster drills (Loosanoff, 1960). A method was sought that would kill oyster drills, but would not harm oysters, clams, *Mercenaria mercenaria*, and other organisms on a shellfish bed, and also would not leave residues in tissues of shellfish that would be harmful to man. Tests were made in the laboratory and the field.

Laboratory Tests

Loosanoff, MacKenzie, and Shearer (1960a, 1960b) reported that chlorinated benzenes, such as monochlorobenzene, orthodichlorobenzene, paradichlorobenzene, trichlorobenzene, tetrachlorobenzene, and their mixtures, are toxic to several species of marine gastropods, including the thick-lipped drill, *Eupleura caudata*, and the Atlantic oyster drill, *Urosalpinx cinerea*. These chemicals were selected for further tests because they were toxic to snails, virtually insoluble in sea water, and of sufficient density to settle to the bottom of the Sound. The last two characteristics reduced the chance of damage to any but bottom-dwelling organisms whose soft parts contact the chemicals directly. Small quantities of Sevin (1-naphthyl-

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N-methylcarbamate) were added to the chlorinated benzenes to increase their killing effect on the snails. In laboratory experiments, orthodichlorobenzene mixed with dry sand in the ratio of 1 to 19, by volume, and then spread over shallow pans killed most oyster drills; and when used to form a barrier in small troughs it prevented them from crossing the barrier for several months.

Loosanoff, MacKenzie, and Davis [1] stated that for 14 months small barriers consisting of orthodichlorobenzene and sand continued to affect oyster drills on contact but were not toxic to larvae and juveniles of sea squirts, *Molgula manhattensis*, common shipworms, *Teredo* sp., Atlantic oyster drills, eastern white slippers, *Crepidula plana*, and mud blister worms, *Polydora* sp., which set and grew within 2.5 cm. (1.0 inch) of the barriers. These observations showed that orthodichlorobenzene was only a contact poison. In large outdoor troughs siltation reduced the effectiveness of chlorinated benzenes by forming a covering layer that kept the oyster drills from touching the chemicals.

Field Tests

Loosanoff (1961) reported that oyster drills can be greatly reduced in numbers by spreading chemically treated sand over shellfish beds. The combination that gave good results consisted of 95 percent dry sand and 5 percent orthodichlorobenzene containing 1 to 3 percent, by weight, of Sevin. The chemicals were mixed with the sand in large commercial cement trucks. The treated sand, loaded on the deck of a boat, was then spread over the oyster bed by a high-pressure stream of water.

Davis, Loosanoff, and MacKenzie [2] reported the results of treatments of several small oyster beds. They emphasized the effects of chemical treatments on organisms other than oysters and clams. On July 16, 1961, a bed of about 1.6 ha. (4 acres) in Great South Bay, Long Island, N.Y., was treated with 9.5 kl. per hectare (5 yards per acre) of sand mixed with 1.9 hl. (50 gallons) of orthodichlorobenzene containing 6 kg. (13 pounds) (2 percent by weight) of Sevin. As the sand descended, several small fish were killed and common jellyfish were carried to the bottom. Shortly after the sand reached the bottom, sea squirts were found partially contracted; oyster drills and other snails were greatly swollen; and a number of hermit crabs, *Pagurus* sp., and mud crabs, *Neopanope texana*, were dead. They did not determine whether this experimental treatment eventually killed the oyster drills. Another bed, which was off the east end of Long Island in 9 m. of water, was treated in like manner. Because of strong water currents over the area, little sand actually reached the bottom that was to be treated and, as a result, the treatment was not effective. This failure indicated that in an area with strong currents it was very difficult to control oyster drills with sand treated with a chlorinated benzene.

In treatments along the Connecticut shore the effects of the chemicals on animals inhabiting the bottom varied somewhat depending on location of the bed. In open waters, divers noticed only a small effect on fish, hermit crabs, mud crabs, and annelids. In areas where waters were shallower and currents slower, however, the effect was greater. In all tests, fish, hermit crabs, and mud crabs fed and moved normally in an area within a few days after a treatment. Fish, perhaps attracted by the exposed white feet of swollen gastropods, were more numerous after a treatment. Most pelagic common shrimp that were in the immediate area at the time the treated sand was spread were apparently killed. Once the chemicals were on the bottom, however, shrimp moved in again and remained uninjured. Oysters and mussels, *Mytilus edulis*, when present, were pumping normally within an hour of the treatment. Starfish, *Asterias forbesi*, were irritated by treated sand falling on their aboral surface, and small sores soon appeared. In a number of treated areas starfish consumed swollen oyster drills and northern moon shells, *Polinices* sp. Davis et al.[3] also reported that the treatment did not reduce the intensity of setting of oyster and starfish larvae in the area.

Polystream[4] (trademark of Hooker Chemical Corporation for a mixture of polychlorinated benzenes containing a minimum of 95 percent total of active trichlorobenzene, tetrachlorobenzene, and

[1] Loosanoff, V. L., C. L. MacKenzie, Jr., and H. C. Davis. 1960. Progress report on chemical methods of control of molluscan enemies. Bur. Commer. Fish. Biol. Lab., Milford, Conn., Bull. 24 (8), 20 pp.

[2] Davis, H. C., V. L. Loosanoff, and C. L. MacKenzie, Jr. 1961. Field tests of a chemical method for the control of marine gastropods. Bur. Commer. Fish. Biol. Lab., Milford, Conn., Bull. 25 (3), 9 pp.

[3] See footnote 2.

[4] Trade names referred to in this publication do not imply endorsement of commercial products.

pentachlorobenzene, and having a last crystal point of 18° C. ± 3° C.), a less expensive product than orthodichlorobenzene, was used for the first time on experimental beds in New Haven Harbor, Conn., in the summer of 1961. I made field tests to compare the effectiveness of orthodichlorobenzene and Polystream and to determine the minimum quantity of chemically treated sand needed to control oyster drills. Sevin was added to both types of polychlorinated benzenes at the rate of 2 percent by weight, and a total of 1.9 hl. of either orthodichlorobenzene or Polystream was mixed with each 9.5 kl. of sand. The two chemical-sand mixtures were spread over eight 0.4-ha. beds at rates of 1.9, 5.1, 9.5, and 19 kl. per hectare. Drill traps were used to estimate the effects of treatments on populations of oyster drills and mud crabs.

SCUBA divers studied the effects of these treatments. Their observations indicated that treatments of 9.5 and 19.0 kl. per hectare of either orthodichlorobenzene and Sevin or Polystream and Sevin caused all visible gastropods, including thick-lipped drills, northern moon shells, knobbed whelks, *Busycon carica*, channeled whelks, *Busycon canaliculatum*, and New England nassas, *Nassarius trivittatus*, to become swollen (snails listed in order of importance as shellfish predators; the New England nassa is not a predator). Apparently, the latter three species of predators were compelled to emerge from their usual position buried in the bottom. A number of pipefish, *Syngnathus fuscus*, mud crabs, and shrimp were either partially paralyzed or behaved abnormally. Small flounders, *Pseudopleuronectes americanus*, however, swam around apparently unharmed. Three days later these effects were more evident; all visible gastropods were either swollen and being eaten alive by starfish or they had already died. The pipefish, mud crabs, and shrimp, nevertheless, had either recovered or had been replaced by others from surrounding areas. Subsequent observations revealed that starfish were gradually consuming the remaining swollen gastropods. Thus, the area was left with a large number of empty gastropod shells which gradually disappeared; a lot with 42 shells of the northern moon shell per 50 m.^{2} of bottom on July 3, for example, had none by July 18. Presumably, the shells had been occupied by hermit crabs and carried away.

Catches of oyster drills on traps indicated that applications of 9.5 and 19.0 kl. of treated sand per hectare had killed nearly all drills and that the mixture of Polystream and Sevin was more effective than the mixture of orthodichlorobenzene and Sevin. The numbers of mud crabs on traps before and after treatments indicated that they were not harmed by the treatments. As a result, we thereafter used Polystream exclusively, abandoned orthodichlorobenzene, and standardized the treatment rate at 9.5 kl. per hectare.

Increased catches of drills, along the borders of lots several weeks after the treatment, indicated that drills were migrating into the lots from surrounding areas. This observation suggested that to ensure protection of an oyster bed from oyster drills, a zone perhaps 25 or more meters wide outside the bed, as well as the bed itself, should be treated, and that treatment of a single large bed would be more efficient than treatment of a number of small beds.

Polystream was used to treat beds inhabited by oysters and clams that are later consumed by humans. It was necessary, therefore, to determine whether these shellfish retained any residues of this chemical. In practice, however, only those beds with seed oysters on them are treated with Polystream. These oysters are transplanted to untreated beds at least 4 months before harvest. It was also desirable to know whether other organisms inhabiting treated beds, particularly those that might be taken by sport or commercial fishermen, retain residues of Polystream.

To determine whether oysters, clams, or other animals or plants accumulated and then lost residues of Polystream, I studied specimens that were collected from treated beds by divers or by dredging. I also studied northern lobsters, *Homarus americanus*, in cages to determine whether residues would be lost after a period of time in water free of Polystream. The U.S. Testing Company of Hoboken, N.J., determined the quantity of Polystream in tissues of the plants and animals through use of a technique developed by Schwartz, Gaffney, Schmutzer, and Stefano (1963).

In 1961 and 1962, I determined the quantities of Polystream in oysters and clams from a 0.4-ha. lot, treated with 1.9 hl. of this chemical. In oysters the residue was 1.8 p.p.m. (parts per million) 8 days after the treatment. It diminished slowly until none was detected 119 days later. Residues in clams

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TABLE 1.—*Residues of Polystream in oysters and clams on a 0.4-hectare bed in New Haven Harbor, Conn., after it was treated with Polystream-sand, June 27–29, 1966*

Time after treatment	Residues	
	In oysters	In clams
Days	*P.p.m.*	*P.p.m.*
8	1.8	1.1
14	2.3	1.7
28	0.2	0.6
56	0.3	0.3
77	0.7	0.7
119	<0.1	<0.1
336	<0.1	<0.1
455	0.1	0.1

were at similar levels and were lost at similar rates (table 1).

Oysters removed from a treated bed and replanted on an untreated area lost any residue of Polystream within a week. Nevertheless, the first few times oysters that had once grown on a treated bed were to be harvested, they were analyzed for any possible residue of Polystream before clearance for marketing. None of these oysters had residues.

In 1966, I determined the rates of loss of Polystream in oysters at several distances from lot 42, Norwalk, which was treated on August 24, 1966, and where strong currents had washed many granules off the lot. After 8 days, residues were as high as 0.3 p.p.m. in oysters 150 m. from the lot and were higher in oysters closer to the lot. On October 13, however, only those oysters 15 m. or closer to the lot showed any residue. At this distance the level had dropped from 1.7 p.p.m. in September to 0.2 p.p.m. On December 8, 106 days after the treatment, no residues were detected in any oysters outside the treated lot (table 2).

To determine the quantity of Polystream in tissues of other organisms inhabiting an oyster bed,

TABLE 2.—*Residues of Polystream in oysters collected at various distances from lot 42, Norwalk, Conn. Lot was treated on August 24, 1966*

Distance from lot 42	Date of collection (1966)		
	Sept. 1	Oct. 13	Dec. 8
M.	*P.p.m.*	*P.p.m.*	*P.p.m.*
15	1.7	0.2	<0.1
30	0.4	<.1	<.1
75	0.2	<.1	<.1
150	0.3	<.1	<.1

I made periodic collections from treated beds. All species of animals or plants collected within a year had accumulated a small quantity of Polystream. Residues of Polystream eventually diminished in those species, namely, the bay scallop, *Pecten irradians*, hermit crab, and sea lettuce, *Ulva* sp., where comparisons between time intervals were made (table 3).

By holding northern lobsters in a cage for a week in the center of a bed 45 days after it was treated, I found that they do accumulate a small residue of Polystream (1.4 p.p.m.) when retained in a treated area. A group of lobsters held on the treated lot for a week and then held on an untreated area for another week did not have any residue. Thus, lobsters may accumulate a small quantity of Polystream while they inhabit a treated bed, but they lose it soon after they leave the bed.

To determine mortality rates of oysters because of possible predation by oyster drills on treated beds, divers collected oysters periodically on several beds. The divers either swam across the center of beds for a distance of perhaps 150 m., gathering about 30 clusters of oysters randomly, or they collected oysters and all other material from within a metal ring enclosing either 1 or 1.5 m.^{2} of bottom from 10 different sections.

TABLE 3.—*Residues of Polystream in animals and plants inhabiting oyster beds in Conn. and N.Y. treated with Polystream*

Animal or plant	Location	Time after treatment	Residue
		Days	*P.p.m.*
Northern puffer (*Sphaeroides maculatus*)	New Haven (State spawning bed)	31	5.9
Sea robin (*Prionotus carolinus*)	New Haven (State spawning bed)	25	8.4
Sand shark (*Carcharias taurus*)	New Haven (lot 152)	8	5.0
Starfish (*Asterias forbesi*)	New Haven (lot 15)	30	1.8
Bay scallop (*Pecten irradians*)	Sag Harbor (lot S)	6	13.6
Bay scallop	Sag Harbor (lot S)	250	0.9
Northern moon shells (*Polinices* sp.)	Northport (lot 1)	1 hour	50.0
Hermit crab (*Pagurus* sp.)	New Haven (lot 152)	1	12.3
Hermit crab		25	2.2
Mud crab (*Neopanope texana*)	New Haven (lot 152)	1	20.5
Red sponge (*Microciona prolifera*)	New Haven (lot 13)	25	2.3
Spaghetti grass (*Codium fragile*)	Sag Harbor (lot S)	250	0.1
Sea lettuce (*Ulva* sp.)	New Haven (lot 152)	1	8.9
Sea lettuce	Sag Harbor (lot S)	6	0.3

EXPERIMENTAL RESULTS IN OTHER AREAS

Wood and Roberts (1963) reported that in the laboratory Polystream alone killed 50 to 78 percent of large Atlantic oyster drills from the Eastern shore of Virginia and that a mixture of Polystream and Sevin killed 66 to 77 percent. Thus, they felt that Sevin was not needed. They also indicated that if oyster drills are in poor condition, they are more easily killed by Polystream. Therefore, they recommended that treatments should be made in the early spring when oyster drills are emerging from winter dormancy.

Haven, Castagna, Chanley, Wass, and Whitcomb (1966) reported the results of a field test in Hog Island Bay, Va. A 0.4-ha. section of bottom was treated with 9.5 kl. of sand mixed with Polystream containing 2 percent of Sevin. The oyster drills were not killed by the treatment, they deposited egg cases at a normal rate, and they destroyed as many oysters on the treated plots as on untreated control plots. I believe the reason for the ineffectiveness was that the treated sand soon sank as deep as 4 cm. into a layer of silt on the bed; thus, the drills could move over the bottom without contacting significant quantities of the chemicals. Haven et al. (1966) also reported that the Polystream-Sevin treatment had a deleterious effect on other living organisms and that growth of oysters and clams was apparently retarded.

RESULTS OF COMMERCIAL TREATMENTS

I used several methods to evaluate the effectiveness of treatments in killing oyster drills and their effects on organisms inhabiting oyster beds. Ten commercial treatments of oyster beds are described.

METHODS USED IN EVALUATION

Oyster companies used a standard rate of 1.9 hl. of Polystream per hectare (50 gallons per acre) of oyster bed. In early treatments, they mixed Sevin with Polystream at the rate of 2 percent by weight. The Polystream was mixed with either dry sand or a granular clay [the mixture is termed Polystream (Granular)] which carried it to the bottom and dispersed it.

Several techniques were used to evaluate the effects of treating commercial oyster beds with Polystream and Sevin. On numerous occasions SCUBA divers examined each bed carefully for 20 to 30 minutes to determine the gross effects of the chemicals on all visible living animals and plants. Often they made the first examination within an hour of a treatment and followed it by many subsequent periodic examinations during the next 2 to 3 years. They examined certain beds once a month during collections to determine survival rates of oysters.

In 1961–63, drill traps were used to estimate the effectiveness of treatments in controlling oyster drills. Because mud crabs enter drill traps in large numbers, I estimated the effect of treatments on these populations.

From 1964–67 I made quantitative determinations of the number of drills per unit area with a hydraulic sampler, which pumps through a mesh bag all bottom material from within a ring enclosing areas of 1 or 1.5 m.^{2} All coarse material is retained within the bag, carried to the surface, and sorted. This sampling method, which is carried out by divers, provides an accurate measure of the density of oyster drills and other mollusks on a shellfish bed if enough samples are taken. I took about 25 random samples on beds 2 to 6 ha. in size a few days before and again about a month after a treatment. I determined the percentage of oyster drills killed by comparing their densities before and after treatments. Actually, the Atlantic oyster drills on many beds were too few in number for me to determine the precise percentage of this species killed.

EFFECTS OF TREATMENTS IN DIFFERENT AREAS

Ten commercial treatments in four States were made with Polystream. Each treatment will be described separately by areas.

Area 1: Lewis Gut, Bridgeport, Conn., 1962

Lewis Gut is a long narrow arm of Bridgeport Harbor. The water is about 1 to 3 m. deep at low tide, and maximum currents run at about 4.5 km. per hour (2.5 knots). On June 27 and 29, 1962, an oyster company treated 12 ha. of this area with a mixture of Polystream-Sevin and sand.

Effect on gastropods.—Divers observed that within an hour after the treatment nearly all thick-lipped drills, Atlantic oyster drills, northern moon shells, and both knobbed and channeled whelks

were swollen; a few weeks later most of these gastropods, as well as mud snails, were dead.

To evaluate the number of oyster drills killed, I used drill traps. The catch per trap per week fell from 16 drills before the treatment to 0.4 drill afterwards. One year later the average catch of oyster drills increased, primarily by recruitment of young drills, to about two per trap per week. In 1964, the average catch rose to about 5 per trap per week, again as a result of recruitment by young oyster drills; by July 1965 it rose to 13 per trap per week (fig. 1).

Effect on associated animals.—During 1961, divers observed that only a small number of fish—primarily sea robins, *Prionotus carolinus;* pipefish; flounders; mummichogs, *Fundulus heteroclitus;* and eels, *Anguilla rostrata*—were present in Lewis Gut before or after the treatment. Immediately after the application of chemicals only the pipefish appeared to be affected, i.e., more sluggish than usual. A few hours later, however, mummichogs were dying along the shore as some of the finer sand coated with Polystream was churned up in the water by wave action.

This treatment had a slight effect on several organisms. Hermit crabs were affected to some degree. A number of them had no shells; apparently, a small quantity of treated sand entered the shell and caused enough irritation to compel them to leave. The abdomens of a number of these crabs had been bitten off. Most mud crabs were unaffected, but between 5 and 10 percent were twitching abnormally immediately after the treatment. The treatment also compelled many nereids and nemerteans to emerge from their burrows. A few weeks later all animals not killed by the initial treatment appeared to be normal.

Catches on drill traps indicated that the treatment did not reduce the population of mud crabs. The weekly catch of these crabs on drill traps followed the same pattern each year: Each trap caught an average of about 15 crabs per week in May, June, and July; about 10 crabs during August; and (because of recruitment of young crabs) 18 to 23 crabs in the fall (fig. 2).

Effect on predation.—In midsummer of 1962 an oyster company planted 3,500 hl. (10,000 bushels) of seed oysters in Lewis Gut. Periodic examination of the oysters through early winter showed little loss from predation by oyster drills.

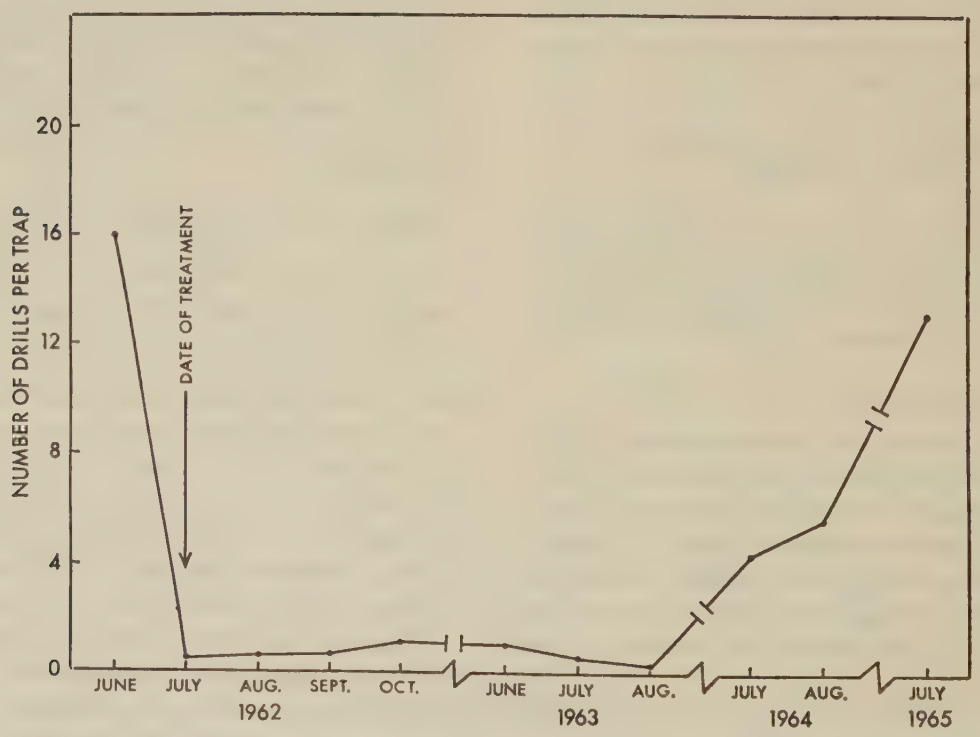

FIGURE 1.—Catches of oyster drills on traps in treated area of Lewis Gut, Bridgeport, Conn.

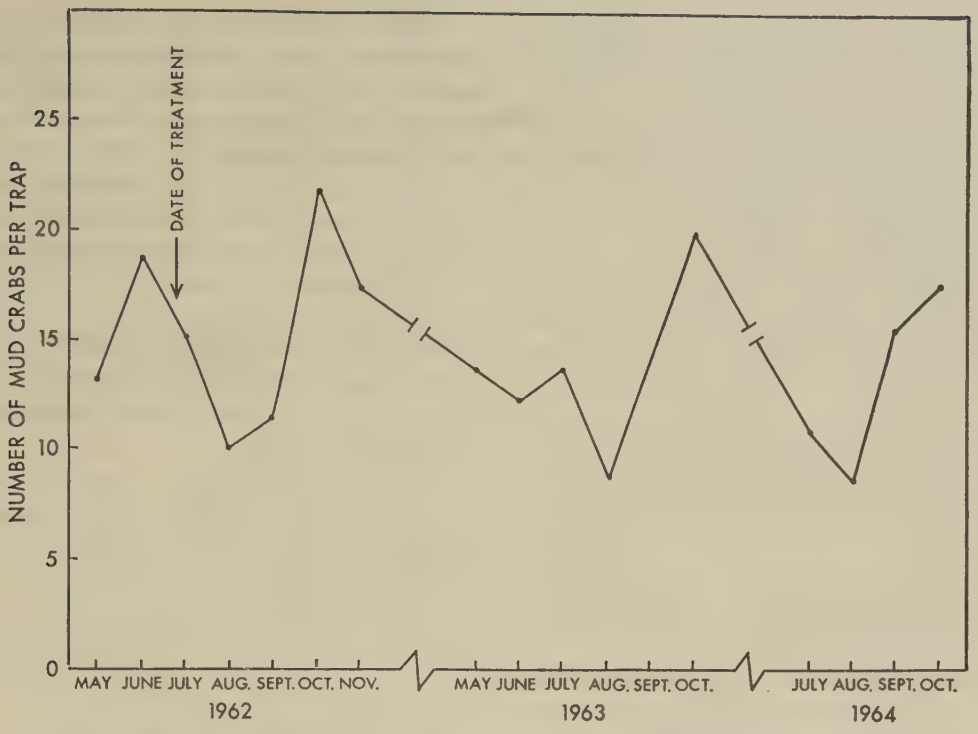

FIGURE 2.—Catches of mud crabs on traps in treated area of Lewis Gut, Bridgeport, Conn.

Area 2: Northport Harbor, N.Y., 1963

Northport Harbor on the north shore of Long Island is about 6.5 km. long. The oyster beds are in water 4.5 to 7.5 m. deep at low tide, and water currents rarely exceed 1.8 km. per hour.

On May 21 and 28, 1963, I made a series of comparative treatments. The purpose was to determine whether Drillex (a mixture of Polystream and 2 percent by weight of Sevin) is more lethal to oyster drills than Polystream alone. The experiment had four 2-ha. lots. Two lots received an application of 11.5 kl. of treated sand per hectare. They were designated as 1 (for Polystream) and 1 x (for Drillex). The remaining two lots which received 19.0 kl. of treated sand per hectare were designated as 2 and 2 x.

Effect on gastropods.—The treatments had a very deleterious effect on gastropods. A few hours after the treatments, divers observed that nearly every visible gastropod on all four lots was swollen; on lots treated with Drillex, however, the drills expanded faster and sooner. Ten days after the treatments, most thick-lipped drills were drawn deeply into their shells but some were still swollen. Northern moon shells were observed in three conditions—partially expanded, dormant with their operculum flush with their aperture, and dead. Twenty-three days after the treatments divers noted that all visible thick-lipped drills were dead on lots 2 and 2 x, and only a small number were alive on lots 1 and 1 x. No northern moon shells were observed either dead or alive; even their shells were gone. Hermit crabs had probably carried them off the bed.

Because many flounders were swimming over the beds and crabs were numerous when the snails were swollen, these fish had ample opportunity to feed on the paralyzed drills. I observed no snails being consumed, however; instead, they appeared to die directly from the toxic effects of the chemicals.

Examination of the bottom showed that Polystream alone killed almost as many oyster drills as Drillex.

Effect on associated animals.—Divers observed that during the applications of Drillex-sand a small number of flounders, many hermit crabs, shrimp, and annelids were killed; however, 10

days later they saw a large number of healthy flounders (only about 1 percent were still affected) and mud crabs on the two treated beds.

Polystream was used in all later commercial treatments because these experiments showed it was much less toxic than Drillex to associated animals, particularly arthropods.

Effect on predation.—I made no careful quantitative determinations; however, periodic observations of the lot indicated that predation by oyster drills on oysters on the treated lots during 1963 was slight.

Area 3: Northport Harbor, N.Y., 1965

On April 28, 1965, which was 2 years after the initial treatment, lot 1 was treated again with Polystream-sand.

Effect on gastropods.—Eight days after the treatment divers observed that every snail was swollen.

The treatment killed 64 percent of the oyster drills (77.2 percent of the thick-lipped drills and 8.6 percent of the Atlantic oyster drills) and reduced their numbers from 31.5 to 11.4 per m.[2] (table 4).

Effect on associated animals.—Nine days after the treatment divers found 6 stunned adult flounders and one dead juvenile on the bed among about 50 healthy flounders of mixed ages. The only hermit crab they saw was healthy.

Before treatment the number of young clams (5–7 mm. long) on the bed was 158 per square meter; 28 days after the treatment the number of clams was 125 per square meter. Thus, apparently only about 20 percent were killed.

Effect on predation.—I made no quantitative determinations. Periodic observations of the lot indicated, however, that predation by oyster drills during 1965 was slight.

Area 4: Northport Harbor, N.Y., 1966

On May 9, 1966, 3 years after the initial treatment, lot 2 was treated again, this time with Polystream (Granular).

Effect on gastropods.—Three days after the treatment divers found that all thick-lipped drills, Atlantic oyster drills, northern moon shells, and New England nassas were swollen.

The treatment killed 92 percent of the oyster drills (94.5 percent of the thick-lipped drills and 71.7 percent of the Atlantic oyster drills) and reduced their numbers from 27 to 2.1 per square meter (table 4).

Effect on associated animals.—No observations were made by divers.

Effect on predation.—I made no careful quantitative determinations. Several observations of the lot indicated, however, that predation by oyster drills during 1966 was slight.

TABLE 4.—*Density of oyster drills, before and after treatments with Polystream and sand or Polystream (Granular), on oyster lots in N.Y., Conn., R.I., and Mass., 1965–67*

Lot no. and area [1] (hectares)	Date of treatment	Formulation	Drills per m.[2]				Killed [4]		
			Before treatment		After treatment				
			E. caudata	*U. cinerea*	*E. caudata*	*U. cinerea*	*E. caudata*	*U. cinerea*	Both species combined
			Number	*Number*	*Number*	*Number*	*Percent*	*Percent*	*Percent*
25 (3.2)	4/30/65	Poly-sand	3.3	0.9	0.0	0.5	100.0	46.6	88.7
1 (2.4–3.2)	4/28/65	Poly-sand	25.2	6.3	5.7	5.7	77.2	8.6	64.0
2 (2.0)	5/9/66	Poly (Gran.)	24.1	2.9	1.3	0.8	94.5	71.7	92.3
205 (1.6)	9/15/66	Poly (Gran.)	[3] 4.0		[3] 0.9				77.5
18 [3]	4/ ?/67	Poly (Gran.)	7.5	0.9	2.4	1.6	68.0		52.0
40 [3]	4/29/67	Poly (Gran.)	12.0	4.7	2.2	1.6	82.2	66.7	77.8
49 [3]	4/29/67	Poly (Gran.)	5.6	0.7	0.9	0.0	84.6	100.0	86.4
42 (2.8)	5/ 1/67	Poly (Gran.)	3.0	0.3	0.9	1.0	66.7		43.5
50 [3]	5/ 1/67	Poly (Gran.)	12.6	1.3	1.7	0.6	86.4	55.6	83.5
19	Control	None	18.8	0.7	19.5	1.7			
RI (0.8)	5/ 1/07	Poly (Gran.)	0.0	6.5	0.0	0.0		100.0	100.0
FP (0.08)	5/29/67	Poly (Gran.)	0.0	40.8	0.0	2.2		94.5	94.5
FP	Control	None	0.0	37.2	0.0	33.2			

[1] Lot 25, Oyster Bay, N.Y.; Lots 1, 2, Northport, N.Y.; Lots 205, 18, 40, 49, 42, 50, and 19, Norwalk, Conn.; RI, Charlestown Pond, R.I.; FP, Fresh Pond Mass.

[2] Actual number of hectares treated on these beds is unknown, but I estimated that areas treated ranged between 1.2 and 6.0 hectares.

[3] Both species.

[4] If count increased, no percentage is given for this species

Area 5: Sag Harbor, N.Y., 1963

A 0.4-ha. lot along the eastern shore of Shelter Island in Sag Harbor was treated. The water over this lot is about 3 m. deep at low tide, and maximum currents are about 2.7 km. per hour.

On September 27, 1963, Polystream (Granular) was used for the first time to control oyster drills.

Effect on gastropods.—Within an hour of the treatment divers noticed that all visible snails were at least partially swollen. A week later divers observed many affected thick-lipped drills, Atlantic oyster drills, northern moon shells, and both knobbed and channeled whelks.

Ten drill traps were placed on the treated lot and an adjacent area before the treatment. The traps in each area collected between 200 and 300 oyster drills. After the treatment, traps were examined only once. They collected only 10 oyster drills on the treated area but gathered 127 on the control area. I did not count the two species of drills separately.

Effect on associated animals.—Divers observed that the treatment did not affect associated animals and plants, such as flounders, bay scallops, mud crabs, and sea lettuce.

Effect on predation.—No determinations were made.

Area 6: Oyster Bay Harbor, N.Y., 1965

Oyster Bay Harbor on the north shore of Long Island is about 8 km. long. The oyster beds are in water from 3.5 to 10 m. deep at low tide and water currents do not exceed 2.7 km. per hour.

On April 30, 1965, lot 25, 3.2 ha., was treated with Polystream-sand.

Effect on gastropods.—The divers made no observations. The treatment killed 89 percent of the oyster drills (100 percent of the thick-lipped drills and 46.6 percent of the Atlantic oyster drills) and reduced their numbers from 4.2 to 0.5 per square meter (table 4).

Effect on associated animals.—The divers made no observations.

Effect on predation.—Lot 25 was planted with small oysters in 1965, 1966, and 1967. Each year oysters were grown on the bed during their first summer of life and then transplanted to another bed the following spring. When first planted in June, July, August, and early September, the oysters were about 5 to 10 mm. long. By late November most of them had grown to 40 to 60 mm.

Predation on the oysters was light in each of the 3 years. On October 1, 1965, examination of the bed showed that less than 5 percent of the oysters had been killed by oyster drills and starfish combined. On July 22, 1966, divers observed that no oysters had been drilled. By October 9, 1967, oyster drills and starfish had killed 4.3 percent of the oysters on one section of the lot and 8.1 percent on another section. Predation by starfish was responsible for most of the mortality.

Area 7: Norwalk Harbor, Conn., 1966

Norwalk Harbor is interspersed with several small islands that protect oyster beds in channels and bays from storms. Water over the beds is from 2 to 6 m. at low tide, and the strongest currents run about 3.5 km. per hour.

Lot 42 in Norwalk Harbor was treated with Polystream (Granular) on August 24, 1966. Depth of water at mean low tide averages about 3 m.; maximum current is 3.5 km. per hour. Divers reported that strong currents carried off the lot a portion of the granules.

Effect on gastropods.—Before the treatment, divers counted up to five oyster drills of both species on each cluster of oysters. Within an hour after the treatment all visible thick-lipped drills and Atlantic oyster drills on clusters of oysters were swelling.

On September 8, 1966, 14 days after the treatment, divers observed that most oyster drills attached to clusters of oysters had fallen to the bottom. In a few instances, however, one or two oyster drills that were protected by being attached on the underside of clusters were unaffected and some were feeding on oysters.

On frequent inspections of the lot divers found that most oyster drills remained stunned, in a semiswollen condition, until November. A small number of drills may have recovered before the water dropped below 10° C., the temperature at which they normally become dormant.

As far as divers could determine, the treatment of lot 42 on August 24 did not kill many oyster drills but only immobilized them and prevented them from feeding. I suspected that a higher percentage would have been killed if the treatment with Polystream had been made in late April or early May.

To determine more precisely the effect of Polystream in the summer, however, an oyster company

treated lot 205, in a more protected area. Tidal currents over this lot run at no more than 0.9 km. per hour and, therefore, did not carry off the Polystream (Granular). The water is about 2 m. deep at low tide. On September 15, when the lot was treated, the water temperature was about 21° C.

A month later determinations with the hydraulic sampler showed that the treatment killed 78 percent of the oyster drills (no separation of species was made) (table 4).

Effect on associated animals.—On lot 42, divers reported that a large number of pipefish, juvenile flounders, mud crabs, and shrimp were stunned by the chemical an hour after the treatment, but these animals appeared to be normal later. They made no observations on lot 205.

Effect on predation.—In early May 1966, lot 42 was planted with 350 hl. of 1-year-old oysters (5,000–6,000 individuals per bushel). On June 17, 7 weeks later, oyster drills had killed 4.3 percent of the oysters and had reduced the number of live oysters per cluster from 19 to 18.2.

By July 25, 12 weeks after the planting, the rate of kill by oyster drills had increased tremendously. For example, 34 percent of the oysters had been killed around the edges of the bed and 26 percent in the center. Thus, during the period of 5 weeks, from June 17 to July 25, the average kill was 4.8 oysters per cluster, or nearly one oyster per cluster per week.

On August 24, the day the lot was treated, a third sampling was made. In areas around the edges of the lot, where oysters were planted thinly, clusters averaged only two live oysters each. In the center of the lot the number of live oysters per cluster averaged between 9 and 10. Thus, even in the main portions of the lot about 50 percent of the oysters had been destroyed. Oyster drills caused almost all the mortality; starfish caused only a small amount.

The fourth sampling was made on September 8. In the main portion of the lot, clusters had an average of ten 1-year-old oysters and, in addition, 18.3 live spat had attached to each cluster. By counting small oyster scars I determined that the original 1966 oyster set had averaged about 30 per cluster. Thus, even in the center of the lot, oyster drills had destroyed more than a third of the 1966 oyster spat by the time of treatment, August 24.

By observing these oysters through the fall of 1966 and into the spring of 1967, I found that virtually no additional oysters were killed by oyster drills. On March 31, 1967, clusters in the main portion of the lot averaged 9.3 2-year-olds (in 1966 they were 1-year-olds) and 21.5 1-year-olds of the 1966 oyster set. No careful determinations were made on lot 205. Later periodic observations indicated, however, that predation by oyster drills was slight.

In the spring of 1967, when these oysters were transplanted to another lot, their volume had increased to 2,100 hl., a sixfold increase during one growing season. I did not determine the increase in size of individual oysters.

Area 8: Norwalk Harbor, Conn., 1967

Five lots in Norwalk were treated with Polystream (Granular) between April 29 and May 13, 1967. Lot 42 was treated again and two lots alongside, lots 40 and 50, were treated for the first time. Depths of water and current velocities are about the same over these three lots. Lots 18 and 49 were also treated for the first time. The depth of water over these lots at low tide is about 2.5 m. and current velocities do not exceed 0.9 km. per hour. Lot 19, adjacent to lot 18, was not treated and served as a control.

Effect on gastropods.—Divers made no observations during or immediately after these treatments.

On lot 18 the treatment killed 52 percent of the oyster drills (68 percent of the thick-lipped drills and apparently none of the Atlantic oyster drills—again, numbers of Atlantic oyster drills were too low for significant comparisons) and reduced their numbers from 8.4 to 4.0 per square meter (table 4).

On lot 40 the treatment killed 78 percent of the oyster drills (82.2 percent of the thick-lipped drills and apparently 66.7 percent of the Atlantic oyster drills—again, numbers of the latter species were too low for accurate appraisal) and reduced their numbers from 16.7 to 3.8 per square meter (table 4).

On lot 42 the treatment killed 44 percent of the oyster drills (66.7 percent of the thick-lipped drills and apparently no Atlantic oyster drills—numbers of Atlantic oyster drills were too low for reliable comparisons) and reduced their numbers from 3.3 to 1.9 per square meter (table 4). Because most

oyster drills were killed on this lot by the second treatment and not by the first in 1966, I believe that treatments in early May are much more effective than those made later in the summer.

On lot 49 the treatment killed 86 percent of the oyster drills (84.6 percent of the thick-lipped drills and apparently all of the Atlantic oyster drills) and reduced their numbers from 6.3 to 0.9 per square meter (table 4).

On lot 50 the treatment killed 84 percent of the oyster drills (86.4 percent of the thick-lipped drills and 55.6 percent of the Atlantic oyster drills) and reduced their numbers from 13.9 to 2.3 per square meter (table 4).

Lot 19, which served as a control, was sampled at the same time as the other lots. The density of oyster drills per square meter was about the same on each date; on May 10 it was 19.5, and on June 30 it was 21.2 (table 4).

Effect on associated animals.—Divers did not examine these lots closely during or immediately after treatment. At intervals during the summer of 1967, however, they observed that healthy flounders, young starfish, mud crabs, and other animals were numerous on the beds. They saw no affected animals. In fact, most animals were more numerous on treated lots than on areas barren of oysters nearby. The divers did not count the young starfish on unplanted areas, but on October 6 they counted 8.8 young-of-year starfish per square meter on lot 18, and 35.3 per square meter on lot 40.

Effect on predation.—I carefully recorded mortalities of oysters on these lots from the time they were planted through November when oyster drills became dormant. In May 1967, 1- and 2-year-old oysters were planted on lot 40 and 1-year-old oysters were planted on lots 42, 49, and 50; and from June through early September, 1967-year-class hatchery-reared seed oysters about 5 mm. in length were planted on lot 18. Losses of oysters because of predation by oyster drills did not exceed 1.5 percent on any of these lots by late November (table 5). Because enough drills were present on some lots to cause higher mortalities—lot 40, for instance, had 3.8 oyster drills per square meter, and lot 50 had 2.3 per square meter—most live oyster drills must have been sufficiently "stunned" by the Polystream to prevent their feeding. This apparent "stunning" effect was also evident on lot 42 in 1966.

Oysters planted on these lots freshly treated with Polystream grew normally. For example, the 1-year-old oysters on lot 50 increased in volume from an average of less than 1 cc. to about 15 cc. each during the 1967 growing season. My determinations of growth of oysters planted on untreated bottoms show that this amount of growth is about normal.

Area 9: Foster's Cove, R.I., 1967

Foster's Cove on the south shore of Rhode Island, about 4 ha. in area, is a tidal pond connected to Charlestown Pond by a narrow inlet. Depth of water over the oysters ranges from 0 to 2 m. at low tide. There is little exchange of water between the two areas; thus, the principal water currents in the cove are caused by winds. Examination of three sections of Foster's Cove on November 10, 1966, indicated that oyster drills had killed about 75 percent of the oysters.

On May 31, 1967, two areas totaling 0.8 hectare were treated with Polystream (Granular).

Effect on gastropods.—Divers made no observations during or immediately after treatment. My later observations showed that the treatment killed all Atlantic oyster drills (no thick-lipped drills were present) in both areas and reduced their numbers from 9.5 and 3.6 to 0.0 per square meter (table 4).

Effect on associated animals.—On June 8, 8 days after the treatment, I examined the areas by walking along the shores and divers also examined them. Along the north shore, perhaps 15 m. from one of the treated areas, there were 4 dead toadfish, *Opsanus tau;* 50 dead silversides, *Menidia menidia;* 500 to 1,000 dead mummichogs; 4 dead blue crabs, *Callinectes sapidus;* 50 dead shrimp;

TABLE 5.—*Percentage of oysters killed by oyster drills and starfish in center areas of lots in Norwalk, Conn., 1967*

[Accumulated monthly totals [1]]

Lot number	May	June	July	Aug.	Sept.	Oct	Nov.
				Percent			
18 [2]	0.0	0.0	0.0	0.6	0.4	1.0	0.2
40 [4]	.0	.0	0.0	1.0	0.0	0.0	.5
42 [3]	.0	.0	0.9	0.5	1.0	0.0	.5
49 [3]	.0	.0	0.0	0.0	0.3	1.5	.0
50 [3]	.0	.2	1.0	0.0	1.0	0.7	.0

[1] Sampling errors account for slight variation in numbers.
[2] Oysters raised in hatcheries in 1967.
[3] 1-year-old oysters.
[4] Mixture of 1965 and 1966 oyster set (1 and 2 years old).

and 10 dead polychaetes. On the inspections made along the shoreline, just inside the other treated section, there were only two dead toadfish and one dead blue crab. Undoubtedly, a high percentage of fish, blue crabs, and shrimp was killed at the time of treatment. Divers did not see any fish or shrimp, live or dead, either on or off treated areas.

Effect on predation.—No determinations were made.

Area 10: Fresh (Quahog) Pond, Falmouth, Mass., 1967

Fresh Pond, about 2.0 ha., is a tidal pond on the east shore of Buzzard's Bay. It is connected with the Bay by a long, narrow creek only about 1 m. wide and 0.3 m. deep at the entrance of the pond. The area for growing oysters is from 0 to 2 m. deep. Winds generate the principal currents in the pond.

On May 29, 1967, a 0.08-ha. section of the pond was treated with Polystream (Granular).

Effect on gastropods.—Within an hour of the treatment divers observed that all snails were beginning to swell.

By July 11, the treatment had killed 95 percent of the Atlantic oyster drills (no thick-lipped drills were present) and reduced their numbers from 40.8 to 2.2 per square meter (table 4).

An untreated area in another section of the pond that served as a control for the treatment had an average on May 29 of 37.2 Atlantic oyster drills per square meter. On July 11 this control plot had 33.2 drills per square meter.

Effect on associated animals.—Because the treatment extended to the shoreline of the pond, a number of observations could be made by walking along the shore. An hour after the treatment I observed 2 flounders (5 cm. long), 5 green crabs, *Carcinus maenas*, and 200 shrimp all dying, and 100 mummichogs stunned. I also observed three small schools of silversides swimming through the area; all these fish were healthy. New England nassas and mud snails, *Nassarius obsoletus*, were beginning to swell.

On July 11, 1967, divers examined the area again. The only animal affected other than snails was a tautog which weighed about 1.8 kg. All New England nassas and mud snails were dead.

Effect on predation.—The area had no oysters.

RECOMMENDATIONS FOR USING POLYSTREAM

During this study I made a number of observations on the use of Polystream (Granular), the form now most commonly used on commercial oyster beds to control oyster drills. These observations are listed below and should be emphasized for those who might wish to use this product:

1. The bed to receive a treatment should have a firm bottom, free of silt.
2. Treatments should be made in late April or early May when oyster drills first become active after a period of winter dormancy.
3. Polystream (Granular) should be spread at slack current.
4. Most successful treatments have been made in water less than 6 m. deep, where currents are less than 2.7 km. per hour. Where currents are stronger than this, planted oysters appear to prevent the Polystream (Granular) from being carried off a bed.
5. Polystream (Granular) treatments are successful on beds planted with seed oysters.
6. In certain shallow areas, where little or no current flows, a smaller quantity of Polystream (Granular) may be successful.

SUMMARY

1. Five experimental and 10 commercial treatments of oyster beds were made with Polystream in the States of Connecticut, New York, Rhode Island, and Massachusetts.

2. Immediately after a treatment, oysters, clams, and other organisms accumulated small residues of Polystream in their tissues. These residues, however, were gradually lost or greatly diminished. For instance, oysters and clams lost the residue of Polystream within 119 days. If they were transplanted from a treated to an untreated bed, however, they lost the residue within a week.

3. All oyster drills were killed in areas where water current velocities were low. On a typical bed, in an area where current velocities were between 0.9 and 2.7 km. per hour, however, about 85 percent of thick-lipped drills and 66 percent of Atlantic oyster drills were killed. Apparently, no oyster drills were killed where current velocities were strong.

4. On treated beds where current velocities were low, significant percentages of fish, small clams,

and other invertebrates were killed. On treated beds where current velocities were between 0.9 and 2.7 km. per hour, treatments killed only small percentages of fish, small clams, crabs, and other invertebrates. A few hours after the treatment the area appeared to be nontoxic to these animals.

5. A higher percentage of oyster drills was killed by treatments made in late April and early May than later in the summer.

6. Oyster drills were killed by the toxic action of Polystream, not by fish or crabs after they became swollen. In a small number of instances, however, they were consumed by starfish.

7. Oyster drills that survived a treatment appeared to be affected by the treatment to the extent that they did not feed significantly for a few months and, thus, did not kill many oysters.

8. The number of oyster drills on a bed where seed oysters were planted and removed each year remained low for at least 2 years.

9. Oyster drills killed less than 2 percent of young oysters during the first year on most treated beds.

10. Growth of oysters appeared to be normal on treated beds. For example, on one bed 1-year-old oysters increased in volume from less than 1 cc. to 15 cc. in one growing season.

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COMPARATIVE DISTRIBUTION OF MOLLUSKS IN DREDGED AND UNDREDGED PORTIONS OF AN ESTUARY, WITH A SYSTEMATIC LIST OF SPECIES [1]

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ABSTRACT

A survey of benthic mollusks in Boca Ciega Bay, Fla., showed a much smaller number and variety of species in the soft sediments in dredged canals than in the predominantly sand and shell sediments in undredged areas. Samples contained an average of 60.5 live mollusks and 3.8 species in undredged areas and 1.1 individuals and 0.6 species in dredged canals. A list of mollusks collected in this survey and in past studies is appended.

This report compares the numbers and varieties of mollusks in fine sediments of dredged canals with those found in undisturbed bottoms of sand and shell in Boca Ciega Bay, Fla. The bay is a shallow coastal lagoon of about 70 km.[2] which connects with Tampa Bay at its southern end (fig. 1). Some of the previous investigations in the lagoon included studies of sediments (Goodell and Gorsline, 1961; Taylor and Saloman, 1969); hydrology (Saloman and Taylor, 1968); submerged vegetation (Pomeroy, 1960; Phillips, 1960); fishes (Springer and Woodburn, 1960; Sykes and Finucane, 1964); and benthic invertebrates (Hutton, Eldred, Woodburn, and Ingle, 1956; Bullock and Boss [2]).

A recent evaluation of the effects of dredging and filling has documented a large loss of estuarine resources in Boca Ciega Bay (Taylor and Saloman, 1968). It was here that scientists and conservationists were finally successful in suppressing a dredge-fill proposal of 202 ha. (Sykes, 1967). This is also the bay in which the U.S. Army Corps of Engineers denied a dredge-fill application for the first time on the basis of fish and wildlife values, thus providing a stimulus for more comprehensive assessments of the biological and recreational aspects involved in future bayfill developments.

Thorson (1956) and others have concluded that sediment composition is a cardinal factor in controlling the settlement and viability of many marine invertebrates. The distribution of sessile benthic mollusks indicates to the marine ecologist the ability of the environment to support life. Marked deficiencies in abundance and variety indicate abnormality of the environment, and the degree of deficiency is roughly proportional to the degree of abnormality.

PROCEDURES

Between September 1963 and August 1964, we took 107 bottom samples at 31 stations in Boca Ciega Bay (figs. 1 and 2). Seven stations were in canals between finger fills (1–7), and the other 24 (8–31) were in relatively undisturbed areas of the bay. We collected algae, sea grasses, and benthic animals with a bucket dredge and bottom drag (Taylor, 1965). In water less than 1 m. deep, three shovelfuls of bay bottom (about 15 l.) were substituted for the dredge haul. One station sample consisted of the combined catch from one bucket dredge (or three shovelfuls) and one bottom drag. At each station a subsample of sediment was taken from the dredge or shovel and was later analyzed at Florida State University.

[1] Contribution No. 57, Bureau of Commercial Fisheries Biological Laboratory, St. Petersburg Beach, Fla. 33706.

[2] Bullock, R., and C. Boss. 1963. Ecological distribution of marine mollusks in Boca Ciega Bay, Florida. Winter term project. Mimeographed report on file at Florida Presbyterian College, St. Petersburg, Fla. 33733.

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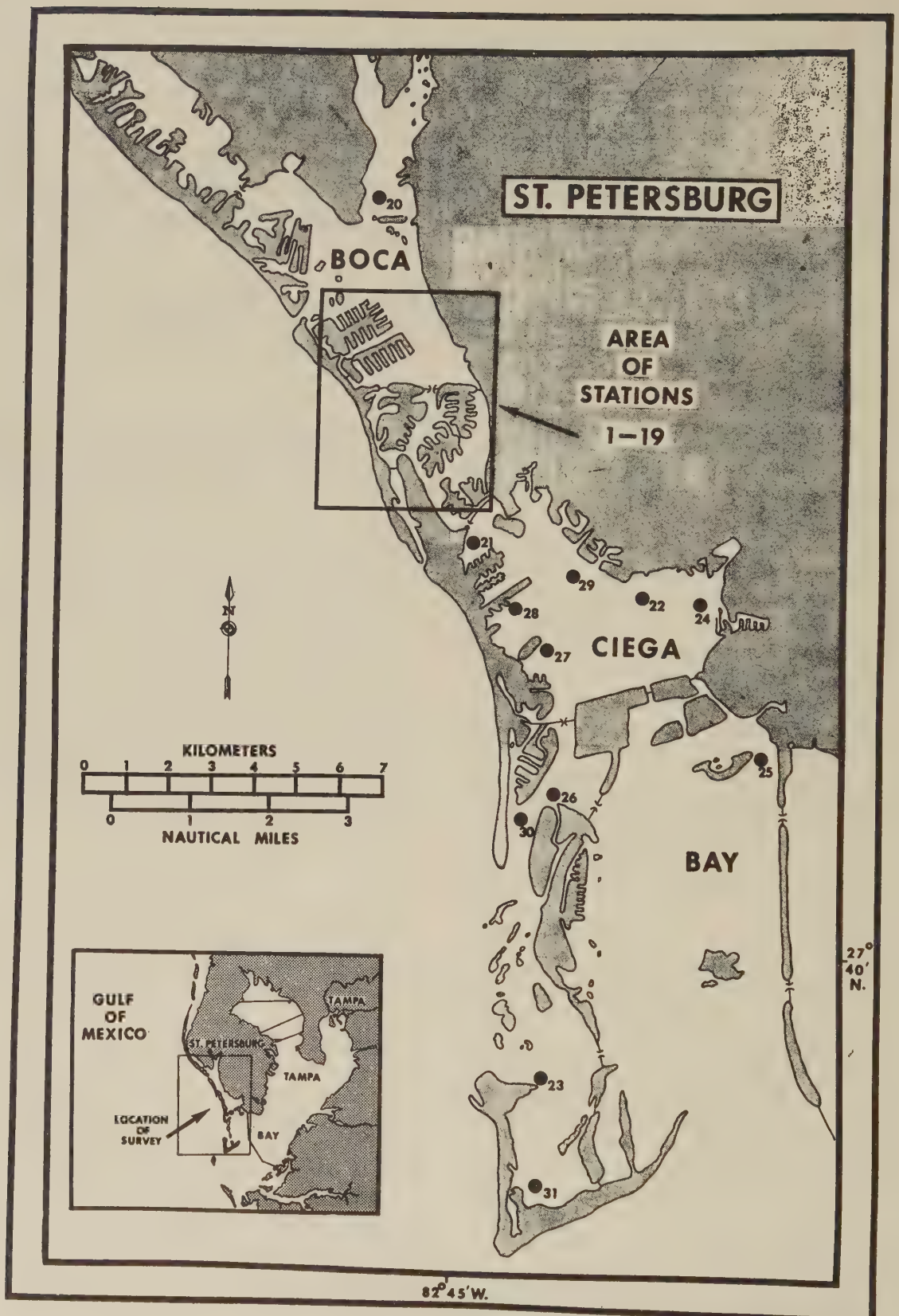

FIGURE 1.—Collecting stations 20 to 31 and area of stations 1 to 19 (see fig. 2), Boca Ciega Bay, Fla.

FIGURE 2.—Collecting stations 1 to 19, Boca Ciega Bay, Fla., between Johns Pass and Corey Causeway.

We washed samples for benthic organisms on a 24-mesh sieve which had an opening of 0.701 mm. and fixed the material retained by the sieve in a 10 percent sea-water Formalin [3] mixture. A protein stain (rose bengal) was added to facilitate the separation of small organisms from debris. Identified animals were preserved in 70 percent isopropanol.

We identified 168 species of mollusks representing 69 families; of these, representatives of 156 species were collected live. We based determinations on standard taxonomic works (Clench, 1941–69; McLean, 1951; Olsson, Harbison, Fargo, and Pilsbry, 1953; Abbott, 1954, 1968; Perry and Schwengel, 1955; Warmke and Abbott, 1962; Keen, 1963; Wagner and Abbott, 1967; an unpublished report by Bullock and Boss (see footnote 2), and collections at the University of

[3] Trade names referred to in this publication do not imply endorsement of commercial products.

South Florida [4] and the U.S. National Museum. Specimens from this study were deposited in the invertebrate reference collection of the BCF (Bureau of Commercial Fisheries) Biological Laboratory, St. Petersburg Beach, Fla.

MOLLUSK-SEDIMENT RELATIONS

Comparison of mollusks and bottom types showed that species and individuals were much less numerous in soft sediments of canals than in sandy sediments in undredged areas of Boca Ciega Bay (tables 1 and 2). Canal sediments, which averaged 85 percent silt and clay, had 16 live mollusks in 14 samples. Living specimens collected at the seven canal stations were the gastropods *Nassarius vibex* and *Haminoea antillarum*, and the pelecypods *Brachidontes exustus*, *Anomalocardia cuneimeris*, and *Mercenaria campechiensis*. These species and 151 others were collected live from the 24 stations in undredged areas of the bay. Sediments from natural bottom, which averaged 91 percent sand and shell, yielded 5,631 live mollusks in 93 samples.

Pratt (1953) suggested that soft sediments and associated hydrological conditions may be limiting because (1) rapid deposition has a smothering effect, (2) high organic content of soft sediments depletes dissolved oxygen, and (3) weak currents in areas of deposition are insufficient for the removal of toxic metabolic wastes. Comparisons of sediments and environmental factors (Taylor and Saloman, 1968) in dredged and undredged areas at sampling stations lead us to conclude that the soft sediment is the principal factor limiting the abundance and diversity of benthic mollusks in bayfill canals of Boca Ciega Bay. Such sediments are as thick as 4 m. in waterways that were dredged 15 years ago.

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[4] Hillman Collection, University of South Florida, Tampa, Fla. 33620.

TABLE 1.—*Depth, bottom type, and number of live mollusks collected at stations in dredged canals in Boca Ciega Bay, Fla., 1963–64*

Canal station	Depth	Bottom type		Species per sample	Individual per sample
		Sand size and larger	Silt and clay		
	M.	*Percent*	*Percent*	*Number*	*Number*
1	4	6	94	1.0	1.0
2	3	7	93	1.0	1.5
3	4	5	95	0	0
4	3	60	40	1.0	2.0
5	6	7	93	0	0
6	4	6	94	.5	1.0
7	4	14	86	.5	2.5
Average	4	15	85	.6	1.1

TABLE 2.—*Depth, bottom type, and number of live mollusks collected at stations in undredged areas of Boca Ciega Bay, Fla., 1963–64*

Stations in undredged areas	Depth	Bottom type		Species per sample	Individual per sample
		Sand size and larger	Silt and clay		
	M.	*Percent*	*Percent*	*Number*	*Number*
8	2.5	98	2	3.5	8.0
9	1.0	99	1	3.0	7.3
10	.5	89	11	.5	.5
11	1.5	97	3	4.0	25.0
12	.5	96	4	.5	2.5
13	2.0	96	4	3.5	18.0
14	1.7	88	12	.5	2.0
15	.5	92	8	2.6	20.6
16	.7	99	1	.3	.7
17	5.0	83	17	1.0	2.5
18	1.5	96	4	6.5	58.0
19	1.0	84	16	1.6	24.0
20	.5	99	1	5.6	140.0
21	1.0	98	2	3.4	67.8
22	2.0	98	2	2.8	71.8
23	7.0	98	2	4.3	66.6
24	2.0	79	19	11.7	316.0
25	.7	97	3	3.2	8.4
26	7.0	99	1	4.0	16.7
27	.7	97	3	5.0	11.0
28	3.0	12	88	4.7	56.3
29	2.0	87	12	6.7	89.0
30	.3	98	2	6.2	78.0
31	2.0	95	5	4.0	86.5
Average	1.9	91	9	3.8	60.5

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APPENDIX

A Checklist Of Mollusks From Boca Ciega Bay, Florida

We identified 168 species of mollusks representing 69 families from BCF collections in Boca Ciega Bay. Of these, members of 156 species were alive. The number was increased to 72 families and 188 species by including mollusks recorded in other studies. The additions are coded within the list by surname initials of the authors who reported them: B. and B.—Bullock and Boss (see footnote 2); H.—Hutton et al. (1956); D. and K.—Dragovich and Kelly (1964). Mollusks not collected alive in this investigation are denoted by an asterisk (*). We identified some specimens only after comparison with specimens in the U.S. National Museum (+). Classifications are based on Abbott (1954, 1968) and Warmke and Abbott (1962).

CLASS GASTROPODA

Fissurellidae

Diodora cayenensis (Lamarck)

Trochidae

**Calliostoma jujubinum tampaense* (Conrad)

Turbinidae

Arene tricarinata (Stearns)
Turbo castaneus (Gmelin)

Neritidae

**Neritina reclivata* (Say)

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Melanellidae

Melanella bilineata (Alder)
Melanella intermedia (Cantraine)

Epitoniidae

Epitonium angulatum (Say)
Epitonium hympreysi (Kiener)
Epitonium rupicola (Kurtz)

Rissoidae

Rissoina chesneli (Michaud)

Vitrinellidae

Cyclostremiscus beaui Fisher—further verification pending.
Cyclostremiscus suppressus Dall—futher verification pending.
+*Teinostoma cryptospira* (no author on specimen)—further verification pending.

Truncatellidae

**Truncatella pulchella* Pfeiffer

Turritellidae

Vermicularia fargoi Olsson

Caecidae

Caecum cooperi S. Smith
Caecum pulchellum Stimpson
Meioceras nitidum (Stimpson)

Modulidae

Modulus modulus (Linné)

Cerithiidae

Bittium varium (Pfeiffer)
Cerithiopsis emersoni (C. B. Adams)—B. and B.
Cerithiopsis greeni (C. B. Adams)
Cerithium muscarum Say
Cerithium floridanum Mörch
Seila adamsi (H. C. Lea)

Triphoridae

Triphora nigrocincta (C. B. Adams)

Potamididae

Batillaria minima (Gmelin)

Calyptraeidae

Calyptraea centralis Conrad
Crepidula aculeata (Gmelin)
Crepidula fornicata (Linné)
Crepidula maculosa Conrad
Crepidula plana Say

Strombidae

Strombus alatus Gmelin—B. and B.

Naticidae

Natica pusilla Say
Polinices duplicatus (Say)
Sinum perspectivum (Say)—B. and B.

Muricidae

Eupleura sulcidentata Dall
Murex cellulosus Conrad
Murex pomum Gmelin
Thais haemastoma floridana (Conrad)—B. and B.
Urosalpinx perrugata (Conrad)

Buccinidae

Busycon contrarium (Conrad)
Busycon spiratum (Lamarck)

Columbellidae

+*Anachis semiplicata* Stearns
Anachis obesa (C. B. Adams)
Anachis ostreicola Sowerby
Columbella rusticoides Heilprin—B. and B.
Mitrella lunata (Say)

Melongenidae

Melongena corona (Gmelin)

Nassariidae

Nassarius vibex (Say)

Fasciolariidae

Fasciolaria hunteria (Perry)
Fasciolaria tulipa (Linné)
Pleuroploca gigantea (Kiener)—H.

Olividae

Oliva sayana Ravenel
Olivella perplexa Olsson
Olivella mutica (Say)
Olivella floralia Duclos

Marginellidae

Bullata ovuliformis (Orbigny)
Hyalina avenacea (Deshayes)
Marginella aureocincta Stearns
Persicula lavalleeana (Orbigny)
Prunum apicinum (Menke)

Conidae

Conus floridanus Gabb—H.
Conus jaspideus Gmelin—H.
**Conus stearnsi* Conrad

Terebridae

Terebra concava vinosa Dall
Terebra dislocata Say
Terebra protexta Conrad

Turridae

**Glyphoturris rugirima* (Dall)
**Monilispira leucocyma* (Dall)
Pyrgocythara hemphilli Bartsch and Rehder
Stellatoma stellata (Stearns)

Bullidae

Bulla striata Bruguière

Atyidae

Haminoea antillarum (Orbigny)
Haminoea succinea (Conrad)

Retusidae

Retusa canaliculata (Say)

Pyramidellidae

Odostomia acutidens Dall
Odostomia impressa (Say)
Odostomia producta Dall
Odostomia seminuda C. B. Adams
Odostomia sp.
Pyramidella crenulata (Holmes)
+*Sayella hemphilli* (Dall)
Turbonilla conradi Bush (Dall)
Turbonilla dalli Bush

Acteocinidae

Cylichna bidentata (Orbigny)

Acteonidae

Acteon punctostriatus (C. B. Adams)

Aplysiidae

Bursatella leachi plei Rang

Ellobiidae

Melampus coffeus (Linné)

CLASS AMPHINEURA

Ischnochitonidae

Chaetopleura apiculata (Say)
Ischnochiton papillosus (C. B. Adams)

Chitonidae

Chiton tuberculatus Linné—H.

CLASS SCAPHOPODA

Dentaliidae

Dentalium eboreum Conrad
Dentalium antillarum Orbigny
Dentalium sp. (resembles *D. texasianum* Philippi)

CLASS PELECYPODA

Solemyacidae

Solemya occidentalis Deshayes

Nuculidae

Nucula proxima Say

Nuculanidae

Nuculana acuta Conrad

Arcidae

Anadara transversa (Say)
**Arca zebra* Swainson
Barbatia cancellaria (Lamarck)
Barbatia candida (Helbling)—D. and K.
Noetia ponderosa (Say)

Glycymerididae

Glycymeris pectinata (Gmelin)

Pinnidae

Atrina rigida Lightfoot

Mytilidae

Amygdalum papyria (Conrad)
Brachidontes exustus (Linné)
Lioberus castaneus (Say)
Lithophaga bisulcata (Orbigny)
Modiolus demissus (Dillwyn)—H.
Modiolus demissus granosissimus (Sowerby)—B. and B.
Modiolus americanus (Leach)
Musculus lateralis (Say)

Plicatulidae

Plicatula gibbosa Lamarck

Ostreidae

Crassostrea virginica (Gmelin)
Ostrea equestris Say
Ostrea frons Linné

Pectinidae

Aequipecten irradians concentricus (Say)

Anomiidae

Anomia simplex Orbigny

Crassatellidae

Crassinella lunulata Conrad

Carditidae

Cardita floridana Conrad
Venericardia perplana (Conrad)
Venericardia tridentata (Say)

Corbiculidae

Pseudocyrena floridana (Conrad)—B. and B.

Erycinidae

Erycina floridana Vanatta
Mysella planulata (Stimpson)

Montacutidae

Montacuta floridana Dall

Lucinidae

**Anodontia alba* Link
Anodontia philippiana (Reeve)
Codakia orbiculata (Montagu)—B. and B.
Lucina multilineata (Tuomey and Holmes)
Phacoides nassula (Conrad)

Diplodontidae

Diplodonta punctata (Say)

Chamidae

**Chama congregata* Conrad

Cardiidae

Dinocardium robustum vanhyningi (Clench and L. C. Smith)
Laevicardium mortoni (Conrad)
Trachycardium egmontianum (Shuttleworth)
Trachycardium muricatum (Linné)

Veneridae

Anomalocardia cuneimeris (Conrad)
Chione cancellata (Linné)
Chione grus (Holmes)
Chione intapurpurea Conrad—B. and B.
Cyclinella tenuis (Recluz)
Dosinia discus (Reeve)
Dosinia elegans Conrad—B. and B.
Macrocallista nimbosa Lightfoot
Mercenaria campechiensis (Gmelin)
Parastarte triquetra (Conrad)
Pitar fulminata (Menke)
Pitar simpsoni (Dall)
**Transennella conradina* Dall
**Transenella stimpsoni* Dall

Petricolidae

Petricola pholadiformis Lamarck

Mactridae

Anatina plicatella (Lamarck)
Mactra fragilis Gmelin
Mulinia lateralis (Say)
Spisula solidissima (Dillwyn)—B. and B.

Tellindae

Psammotreta intastriata (Say)—B. and B.
Macoma constricta (Bruguière)
Tellidora cristata Recluz
Tellina aequistriata Say
Tellina alternata Say
Tellina lineata Turton
Tellina mera Say
Tellina tampaensis Conrad
Tellina sp. (resembles *T. texana* Dall)
Tellina versicolor DeKay

Semelidae

Abra aequalis (Say)
Cumingia tellinoides (Conrad)
Semele bellastriata (Conrad)
Semele proficua (Pulteney)
Semele purpurascens (Gmelin)

Donacidae

Donax variabilis Say

Sanguinolariidae

Tagelus divisus Spengler
Tagelus plebeius (Lightfoot)

Solenidae

Ensis minor Dall

Corbulidae

Corbula barrattiana C. B. Adams
Corbula caribaea Orbigny
Corbula contracta Say

Pholadidae

Cyrtopleura costata (Linné)
Martesia cuneiformis Say

Pandoridae

**Pandora trilineata* Say
Pandora bushiana Dall

Lyonsiidae

Lyonsia hyalina floridana (Conrad)

Periplomatidae

Periploma sp.

EFFECT OF WATER VELOCITY ON THE FISH-GUIDING EFFICIENCY OF AN ELECTRICAL GUIDING SYSTEM

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ABSTRACT

The study was performed in 1962 in a diversion of the Yakima River near Prosser, Wash. Massive structures for regulating the water velocity, producing the desired electrical field, and collecting the guided fish were installed. Evaluation facilities consisted of rotary drum screens to divert all fish that escaped past the electrical field to an inclined-screen trap. The fish tested were wild, downstream-migrating fingerlings of chinook salmon, *Oncorhynchus tshawytscha;* coho salmon, *O. kisutch;* and rainbow or steelhead trout, *Salmo gairdneri*. The variables were three water velocities, three species, and four test periods.

Fish-guiding efficiency tended to decrease with increasing water velocity. The guiding efficiencies of the electrical system at water velocities of 0.2, 0.5, and 0.8 (m.p.s.) meter per second were, respectively, 84.2, 54.2, and 50.2 percent for chinook salmon; 82.4, 47.8, and 42.8 percent for coho salmon; and 69.9, 40.2, and 44.8 percent for rainbow or steelhead trout. The guiding efficiency achieved was, thus, highest with chinook salmon, intermediate with coho salmon, and generally lowest with rainbow or steelhead trout.

The use of electricity to guide juvenile salmon and trout migrating downstream may be feasible in certain environments where the water velocity does not exceed 0.3 m.p.s. but does not appear practical for use in most rivers and streams.

One of the major problems facing fishery agencies in the Pacific Northwest is that of providing an efficient and economically feasible method of guiding juvenile salmon and trout past areas potentially dangerous to fish. The need is particularly acute in river systems affected by high dams and large, deep storage reservoirs. Recent studies (Durkin, Park, and Raleigh, 1970) indicate that under certain conditions many juvenile migrants fail to pass through large reservoirs, implying that if natural runs are to be perpetuated, downstream migrants must be guided and collected at the head of a reservoir or in its tributaries.

Various methods of guiding fish, including the use of electricity (Holmes, 1948; Andrew, Kersey, and Johnson, 1955), louvers (Bates and Vinsonhaler, 1957), and of lights and air bubbles (Brett and Alderdice, 1958) have been tested with varying degrees of success. Mason and Duncan[1] described experiments using the electrical guiding principle in which they successfully diverted about 90 percent of the juvenile migrants. Their experiments, however, were in water velocities of less than 0.3 m.p.s. Because the physical conditions at the upstream end of large reservoirs may vary considerably, a guiding system for the collection of juvenile salmon must operate efficiently under a variety of flow conditions.

The purpose of the present study was to determine the effect of three water velocities—0.2, 0.5, and 0.8 m.p.s.—on the fish-guiding efficiency of an electrical guiding system operating under field conditions.

EXPERIMENTAL SITE

Requirements of the experimental site were: ample flows that could be controlled, readily available electric power, sufficient downstream migrants to carry out the tests, and a convenient system for assessing the total outmigration. A section of the Chandler Canal (fig. 1), a diversion of the Yakima River near Prosser, Wash., met these requirements.

The Chandler Canal is about 2.4 m. deep, 19.8 m.

[1] Mason, James E., and Rea E. Duncan, Development and appraisal of methods of diverting fingerling salmon with electricity at Lake Tapps. Bur. Commer. Fish., Biol. Lab., Seattle, Wash. Manuscript.

Published June 1970.

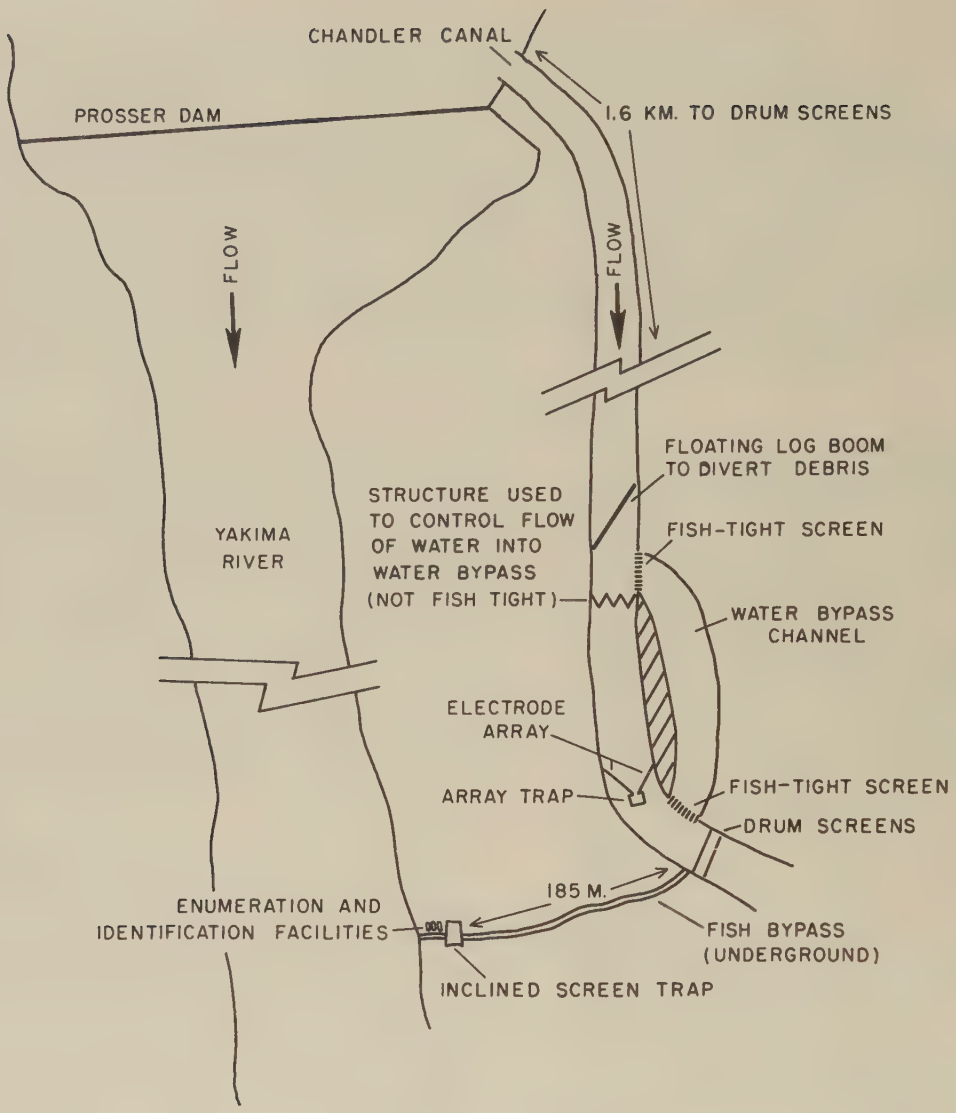

FIGURE 1.—Diagrammatic sketch of experimental site.

wide, and 14.5 km. long; it normally carries a flow of 28.3 to 34.0 c.m.s. (cubic meters per second). The banks have a 60° slope. The bottom consists primarily of sand and silt with some areas of small gravel. The water velocity is relatively uniform because large obstructions are lacking.

The entrance to the canal is not screened; juvenile fish migrating down the Yakima River have easy access, especially during periods of low water when a large portion of the river is diverted into the canal. To salvage these fish, the Bureau of Sport Fisheries and Wildlife operates rotary drum screens and a fish bypass system about 1.6 km. downstream from the canal intake. The experimental site consisted of a 439-m. section of the canal just upstream from the drum screens.

VELOCITY CONTROL STRUCTURES

Stoplogs, shunting panels, and screens were manipulated to effectuate and maintain the desired water velocities (0.2, 0.5, and 0.8 m.p.s.). Figure 2 is an aerial photo of the velocity control structures. A trash boom at the upstream end of the experimental site diverted floating debris to the bank where it was collected for disposal. Just downstream from the boom, flows could be diverted to the water-bypass channel (B, fig. 2),

FIGURE 2.—Physical facilities of experimental fish-guiding site at Prosser, Wash. Waterflow is from right to left. Experimental canal (A) had V-type electrode array, an array trap, and a water-velocity control structure to divert excess flow through water-bypass channel (B). The water-bypass channel was screened at both ends to prevent entry of fish. Arrow points to rotary drum screens used to evaluate fish-guiding efficiency of electrical field created by electrode array. Yakima River is in background.

which was excavated adjacent and parallel to the Chandler Canal.

The bypass channel was about 1.2 m. deep, 288 m. long, and 64 m. wide. It carried the excess flow when reduced velocities were desired in the experimental canal. Both ends of this bypass channel were screened to prevent entry of fish (fig. 3). Each screen support structure consisted of a wooden framework, 72 m. long and 3 m. high, equipped with guides to accommodate 69 individual screens. Each screen was about 0.9 m. wide, 3 m. high, 3.2 mm. thick, and constructed of perforated steel plate. The perforations were 6.4 by 25.4 mm. ovals that provided a 46 percent opening. A traveling hoist on an overhead I-beam was used to lift the screens for cleaning. Each screen bay was fitted with a double set of guides so that a second screen could be installed before the first was removed.

The screen support structure at the entrance to the water-bypass channel was also equipped with guides to accommodate stoplogs. The stoplogs, constructed of concrete, were about 0.9 m. long, 0.6 m. high, and 5.1 cm. thick. An overhead hoist, similar to that used for lifting the screens, was used to raise and lower these stoplogs.

Another structure, at the upstream end of the main experimental canal and just downstream from the entrance to the water-bypass channel, was also used to help regulate the water velocity (fig. 4). This structure was constructed in the form of four V's joined together (VVVV) and was placed in the experimental canal at 90° to the flow. The structure was connected to each bank by earth-filled wooden abutments. The sides of each V were equipped with guides to accommodate 15 solid plywood panels. An overhead hoist raised or lowered

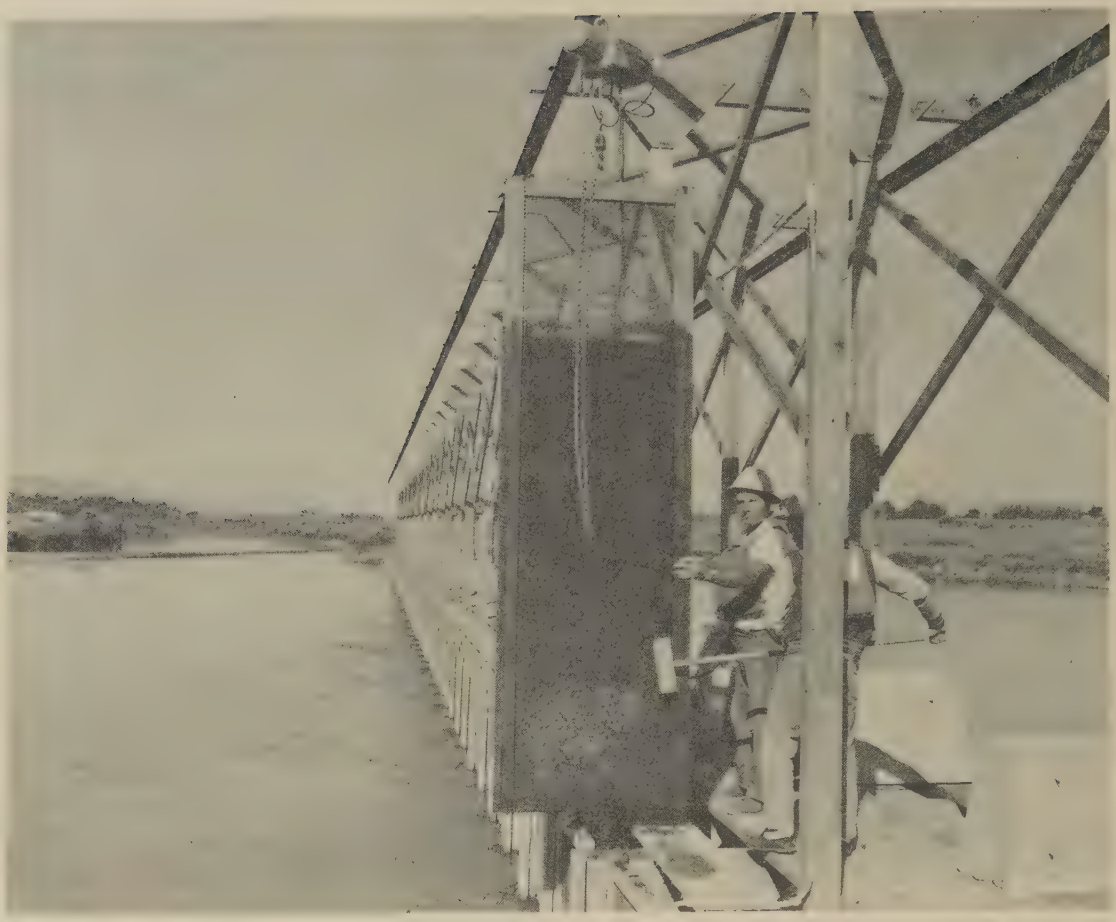

FIGURE 3.—Screen support and velocity control structure at entrance to water-bypass channel. Screen is raised for cleaning. Several concrete stoplogs are stacked in lower right foreground.

the panels. By installing various numbers of these plywood panels and adjusting the stoplogs in the velocity control structure at the entrance to the water-bypass channel, we could divert water to regulate the flow. At the slowest velocity tested—0.2 m.p.s.—the flow was about 7.4 c.m.s.; at 0.5 m.p.s. it was 22.2 c.m.s.; and at 0.8 m.p.s., 37.1 c.m.s. The three test velocities were average velocities and were maintained by routine cleaning of the screens. Actual water velocities varied about ±0.06 m.p.s. from the desired test velocities.

ELECTRODE ARRAY AND ELECTRICAL CONDITIONS

The angle of the electrode array to the water-flow and the electrical conditions of the array were held constant during the entire experiment. The array consisted of three rows of vertically suspended electrodes forming a 30° V (fig. 5). Because the electrode array trap was constructed nearer the right bank, looking downstream, and both legs of the array extended upstream at about a 15° angle to the flow, the legs were not exactly the same length. The left leg was 45.7 m. long, and the right leg 30.5 m. The electrodes were supported on the surface by a wooden framework and on the bottom by wooden dowels. One dowel extended from the bottom of each electrode and was driven into the sandy canal bottom about 10 cm. These dowels helped to keep the electrodes vertical at the higher water velocities and also insulated them from the canal bottom. The electrodes were 3-m. lengths of steel pipe with an outside diameter of 5.1 cm. The distance between the rows of electrodes in each leg of the array was 1.2 m. from the upstream row to the middle row and 0.6 m. from the middle to the downstream row. Spacing between the electrodes was 0.6 m. (fig. 6).

FIGURE 4.—Velocity control structure at upstream end of main experimental canal.

The electrodes were wired to make a total of five groups (fig. 7); when energized, each group produced an electrical field. The applied voltage to all of the electrodes was the same; hence, the voltage gradient created by the electrode arrangement and wiring pattern was higher on the downstream side than on the upstream side of the array. Figure 8 is an analog gradient plot of an electrical field created by one pulse at one specific location on the left side of the electrode array. The plotting interval is 10 percent of the applied voltage. Only one pulse of the five-pulse cycle is illustrated, but it is representative of the electrical fields produced with each pulse, because the wiring pattern was uniform with respect to electrode spacing.

The electrodes were energized with d.c., square-wave pulses, supplied by interrupting the output of a d.c. generator with sequential switching equipment (Volz, 1962). Figure 9 shows a block diagram of this equipment. The pulse amplitude was 125 volts, the duration 20 milliseconds, and the frequency 15 pulses per second. Because the electrodes were wired in five groups and the groups pulsed sequentially, each group was actually energized only three times per second (total pulse frequency divided by number of electrode groups). These electrical conditions had been tested in previous guiding experiments and had proved to be non-injurious to fish (Pugh, 1962).

Table 1 shows the pulsing sequence of the electrode array. When the first pulse was delivered, the electrodes connected to pulse supply cable 1 became positively energized and all the electrodes in the downstream row (pulse supply cable 6) became negatively energized. On the second pulse, the electrodes connected to pulse supply cable 2 became positively energized and the electrodes in the downstream row became negatively energized. This succession of pulses continued through pulse supply cables 3, 4, and 5. When the fifth pulse had been

FIGURE 5.—One leg of electrode array.

delivered, the cycle was complete and the sequential pulsing equipment switched automatically to start the second cycle. During the second and each succeeding cycle, the electrodes were energized in exactly the same manner as they were during the first cycle.

Although the polarity of the electrodes was not alternated, we experienced very little electrolysis. Once the desired electrical conditions had been set into the sequential switching equipment, the gear functioned automatically and dependably for the duration of the experiment.

TABLE 1.—*Pulsing sequence and polarity of the electrode array*

Pulse supply-cable (number)	Pulsing sequence and polarity					
	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Pulse 1 (second cycle)
1	(+)	0	0	0	0	(+)
2	0	(+)	0	0	0	0
3	0	0	(+)	0	0	0
4	0	0	0	(+)	0	0
5	0	0	0	0	(+)	0
6	(−)	(−)	(−)	(−)	(−)	(−)

The purpose of a sequentially pulsed field, sweeping in the direction of the array trap, was to take advantage of any electrotactic effect that the electrical energy might produce. Although the electrode array and electrical conditions in this experiment were designed to divert the fish by stimulating an avoidance response at the periphery of the electrical field, it is known that when fish penetrate a pulsed d.c. electrical field of sufficient intensity they are stimulated to propel themselves in the direction of the positive pole or anode (Haskell, MacDougal, and Geduldig, 1954).

ARRAY TRAP

The array trap was at the downstream end of the electrode array. It was constructed with a 6.4 m.-wide entrance so that the effective electrical fields created by the converging legs of the elec-

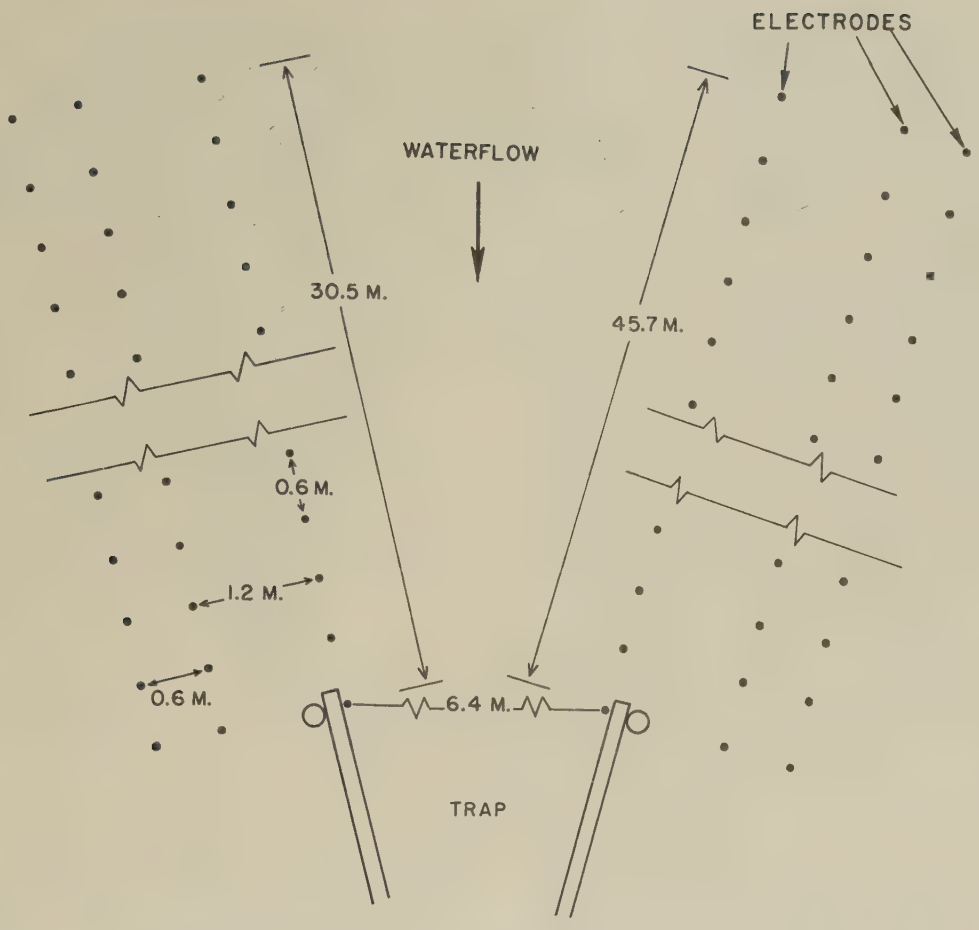

FIGURE 6.—Electrode array with spacing of electrodes as indicated.

trode array would not overlap and prevent the entry of fish. Observations indicated that the electrical field did not affect fish swimming more than 0.9 to 1.2 m. away from the electrodes; hence, any fish migrating in an area about 4.0 m. wide in the middle of the canal were able to enter the array trap without being visibly affected by the electrical energy.

The trap entrance occupied 34 percent of the cross-sectional area of the canal. Measurements showed that when the water velocity in the canal was 0.2 m.p.s., the trap screened about 33 percent of the flow. At higher water velocities the hydraulic head on the trap lead-in screens increased and some water tended to flow upstream around the end of the screens rather than through them. Consequently, the trap screened only about 29 percent of the flow at a water velocity of 0.5 m.p.s. and about 25 percent at 0.8 m.p.s.

The trap lead-ins, converging at a 30° angle (fig. 10) extended downstream from the trap entrance to the trap throat. Each of these lead-ins was 11.6 m. long and consisted of 11 screens of the same design and construction as those used in the velocity control structure at the entrance to the water-diversion channel. An overhead lifting device facilitated the cleaning of the screens. The trap throat was 0.5 m. wide by 2.4 m. deep. It was equipped with guides to accommodate a gate that could be closed when the trap was being emptied.

The trap holding area was about 3 m. wide, 3 m. long, and 2.4 m. deep. It was equipped with a metal brail that was divided into four sections by wooden separators (fig. 11) to facilitate the removal of captured fish. The brail was lifted by a wire rope attached to an electric winch.

EVALUATION FACILITIES

Facilities for evaluating the fish-guiding efficiency of the electrical system were about 150 m.

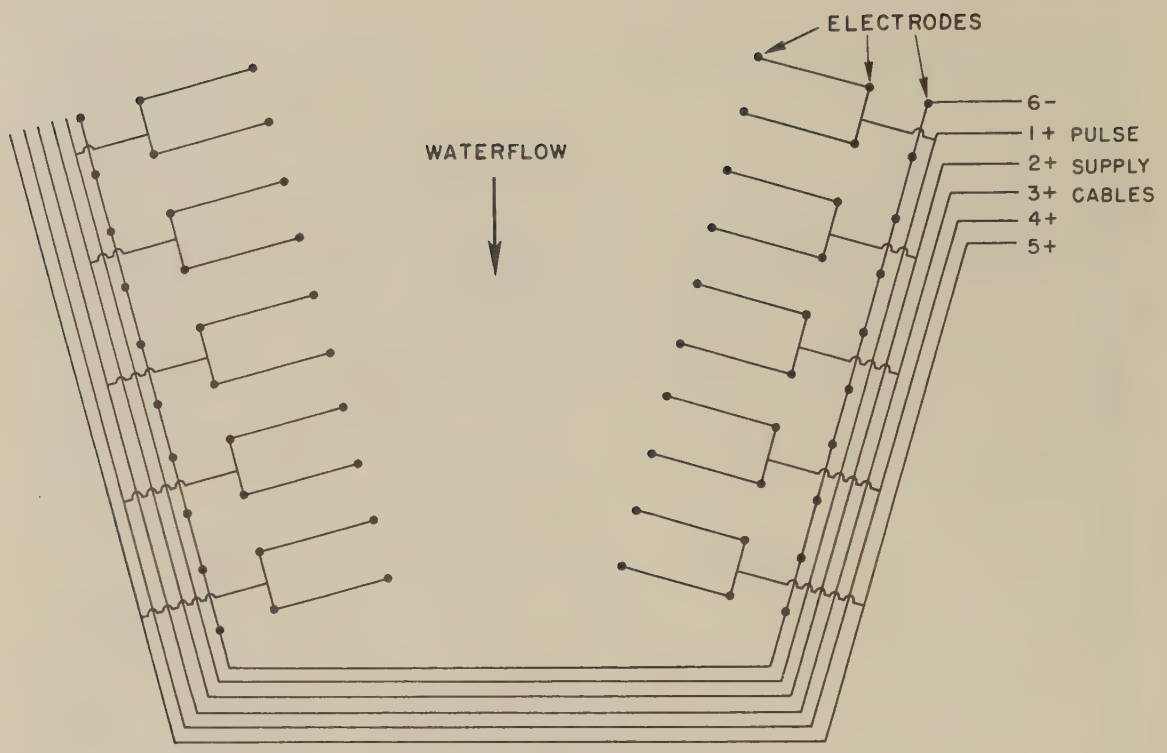

FIGURE 7.—Wiring pattern of electrode array.

downstream from the electrode array trap. All fish escaping past the electrode array were stopped by revolving drum screens (fig. 12), which diverted them to an underground bypass leading to an inclined-screen trap. Four wooden troughs adjacent to the inclined-screen trap held the captured fish while they were being counted and identified. These troughs were 20.3 cm. deep, 22.9 cm. wide, and 167.6 cm. long (fig. 13). Each was divided into three sections by removable screen partitions and fitted with an overflow standpipe at one end. A constant flow was fed to the troughs from a headbox upstream from the inclined-screen trap. The troughs were placed so the end with the standpipe was above an open flume which carried water from the inclined-screen trap to the Yakima River.

EXPERIMENTAL DESIGN

The variables tested were three water velocities (0.2, 0.5, and 0.8 m.p.s.), four test periods (variations among the test periods were due to uncontrollable environmental changes such as temperature, turbidity, and water resistivity), and three species of fish—chinook salmon, *Oncorhynchus tshawytscha;* coho salmon, *O. kisutch;* and rainbow-steelhead trout, *Salmo gairdneri.*[2] Table 2 shows the sequence of tests. The effect of each water velocity on the fish-guiding efficiency of the electrode array was tested once during each period. The experiment ran 50 days (April 21 to June 9, 1962); testing was continuous except for a 1-day interruption due to power failure during an electrical storm.

The effect of each of the three water velocities on the fish-guiding efficiency of the electrical system was determined by comparing the number of individuals of each of the three species of fish captured in the electrode array trap during a specific test period with the total number of the same species taken by the array trap plus the inclined-screen trap during that period.

Water conditions in the experimental canal were checked periodically. Velocity was measured every 2 hours with a Gurley current meter (No. 622–E)[3] at the downstream end near the middle of the

[2] The term rainbow-steelhead trout, as used in this paper, includes both seaward migrants and residual members of the species.

[3] Trade names referred to in this paper do not imply endorsement of commercial products by the Bureau of Commercial Fisheries.

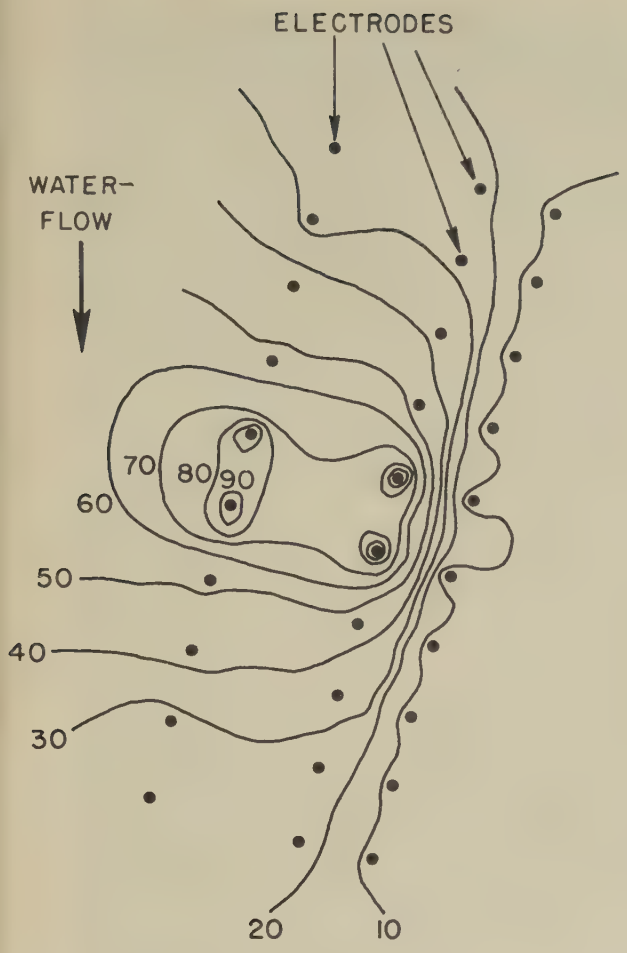

FIGURE 8.—Electrical field created by one pulse at one specific location on the left side of the electrode array. (Lines connect points of equal potential; numbers show percentage of the applied voltage.)

canal. Water temperature was taken three times daily (6:00 a.m., 2:00 p.m., and 10:00 p.m.) with a standard mercury thermometer. The average water temperature was 14.4° C. (range 11.1 to 20.0° C.). Turbidity and resistivity were also measured three times daily. Turbidity averaged 15.6 parts per million silica dioxide (range 10.0 to 26.0 p.p.m.), and the average water resistivity was 5,535 ohm cm. (range 4,290 to 7,400 ohm cm.).

To minimize the escape of fish from the array trap, the catch was removed every 2 hours (e.g., 2:00 p.m., 4:00 p.m.). Fish could not escape from the inclined-screen trap; therefore, it was checked less frequently—at 4-hour intervals (e.g., 4:00 p.m., 8:00 p.m.). This schedule was followed throughout the experiment, even during periods of

TABLE 2.—*Sequence in which different water velocities were tested during four test periods*

Test periods	Dates (1962)	Water velocities		
		M.p.s.	*M.p.s.*	*M.p.s.*
I	April 21–May 3	0.5	0.8	0.2
II	May 3–May 16	.2	.5	.8
III	May 16–May 28	.8	.2	.5
IV	May 28–June 9	.5	.8	.2

maintenance and stoplog manipulation, to ensure that fish were not delayed in their downstream migration. Fish captured in the array trap were transported in an aerated tank to the holding troughs adjacent to the inclined-screen trap where they were counted and identified. Movable partitions within the troughs made it possible to count and identify the fish without handling. The fish were released, after the data from each group had been recorded, by removing standpipes from the troughs and allowing the water and fish to drain into the bypass flume. From the flume, the fish could re-enter the Yakima River. Fish captured in the inclined-screen trap were also identified. counted, and released into the Yakima River.

EXPERIMENTAL PROCEDURE

Before beginning each test, we obtained the desired water velocity by manipulating the concrete stoplogs in the velocity control structure at the entrance to the water-bypass channel and the plywood panels in the velocity control structure in the main canal. This operation required about 8 hours.

Each control test (power off) was started at 4:00 p.m. The array trap and the inclined-screen trap were cleared of fish before the start of the test and then emptied at regular intervals for the duration. The control test lasted 40 hours (until 8:00 a.m. on the second day after the experiment started). The 8 hours following the control test (8:00 a.m. to 4:00 p.m.) were used primarily for maintenance and cleanup. At 4:00 p.m., when the maintenance period ended, the electrode array was energized according to preset electrical conditions. These conditions were monitored during the entire power-on test by means of a calibrated oscilloscope. The power-on test lasted 40 hours (until 8:00 a.m. on the second day after the array was energized); the sequential switching equipment was then turned off and the stoplogs and plywood

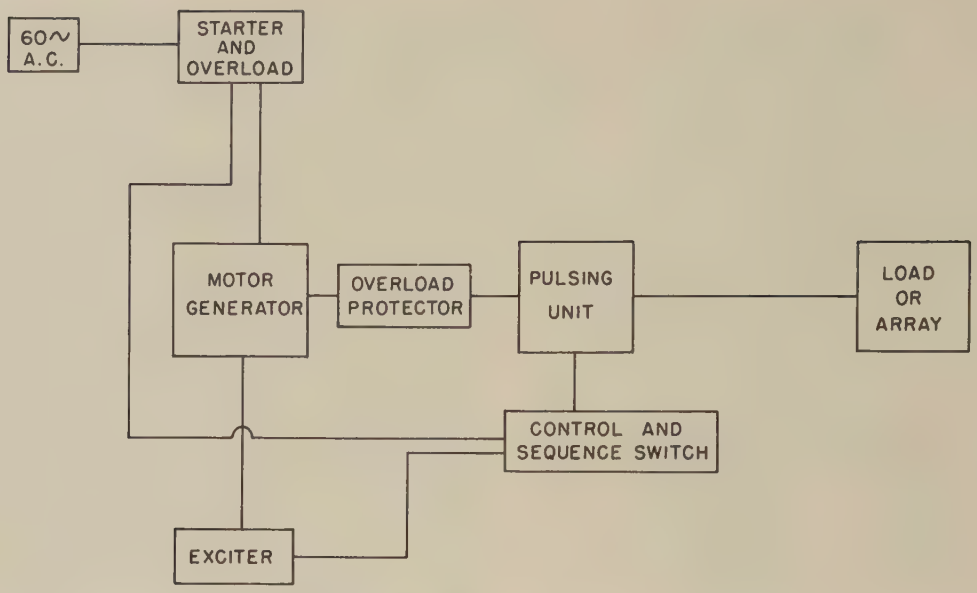

FIGURE 9.—Block diagram of sequential switching equipment used to supply d.c., square-wave pulses.

FIGURE 10.—Lead-in screens and throat (arrow) of array trap.

FIGURE 11.—Electrode array trap with throat closed (arrow) and sectioned brail raised.

panels manipulated to create the desired water velocity for the next test. This procedure was followed for the duration of the experiment. Each complete test took 96 hours: stoplog adjustment, 8 hours; control period, 40 hours; maintenance, 8 hours; and power-on, 40 hours.

COMPOSITION OF CATCH

Most of the test fish were wild, downstream migrants of the Yakima River system. One-hundred twenty-nine thousand juvenile salmon and trout were captured. About 50 percent were chinook salmon, 32 percent coho salmon, and 18 percent rainbow-steelhead trout. The chinook salmon belonged to age-groups 0 and I and had average fork lengths of 89 and 133 mm., respectively. The coho salmon were age-group I fish and averaged 131 mm. The rainbow-steelhead trout were age-group I and older and had a mean length of 198 mm.

EFFECT OF TEST VARIABLES ON EFFICIENCY OF FISH-GUIDING AND COLLECTING

Preliminary analysis indicated that the electrode array and array trap collected a relatively high percentage of fish, even during the power-off (control) conditions. To distinguish between the fish-collecting efficiency of the total guiding system (electrode array and array trap) with the power on and the actual fish-guiding efficiency of the electrode array and electrical field alone, the experimental results are presented in three sections: (1) electrode array energized plus array trap—percentage of fish collected by the electrode array and array trap with the electrode array energized, (2) electrode array nonenergized plus array trap—percentage of fish collected by the electrode array and array trap under control conditions, and (3) electrode array energized without

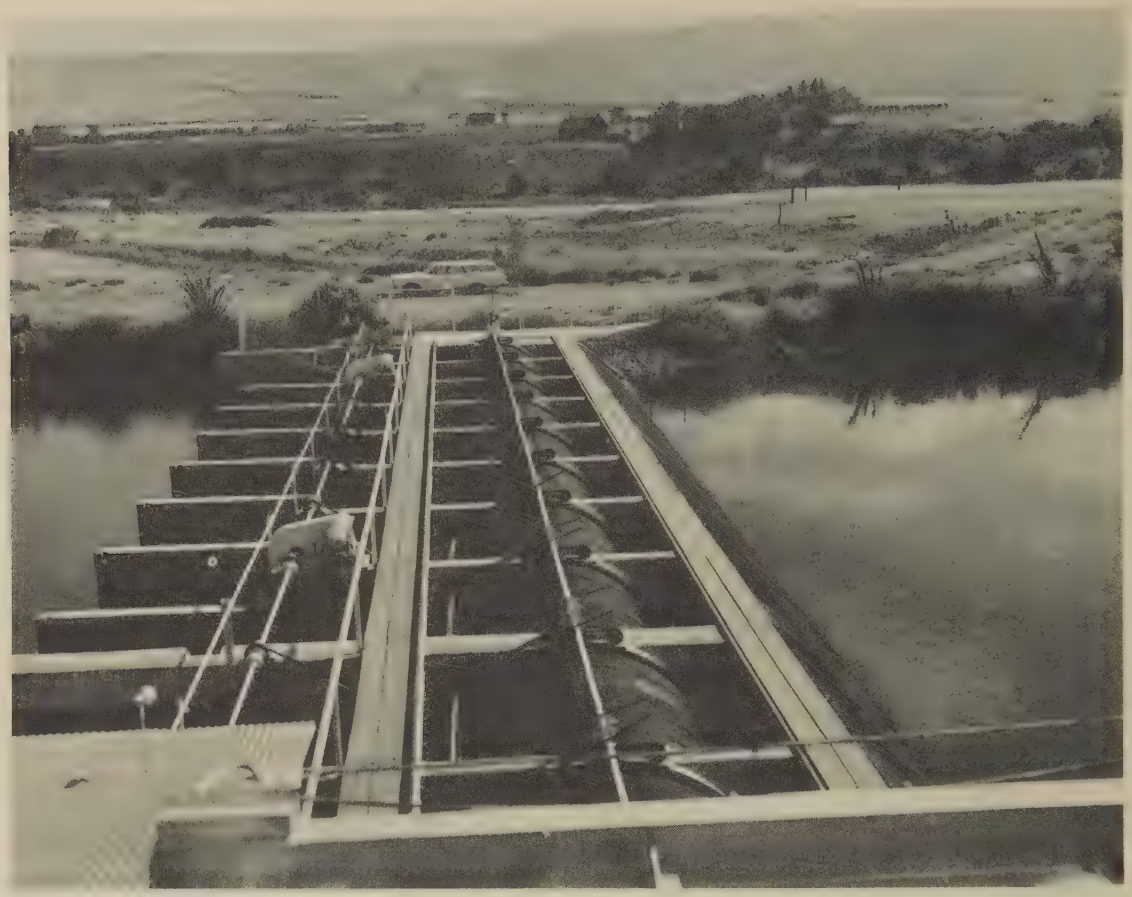

FIGURE 12.—Revolving drum screens used to divert fish that escaped past the electrode array to an inclined-screen trap.

array trap—percentage of fish actually guided by the electrode array and the electrical field created by the electrode array. Details of the methods used to compute these fish-guiding and collecting efficiencies are discussed below.

ELECTRODE ARRAY ENERGIZED PLUS ARRAY TRAP

Table 3 shows the fish-collecting efficiency of the electrode array and array trap with the power on for each test velocity and test period, by fish species. These efficiencies (in percentages) were computed by dividing the total number of each species of fish captured in the electrode array trap during a specific power-on period by the sum of this number plus the number of fish of the same species captured in the inclined-screen evaluation trap during the same power-on period, and multiplying the quotient by 100.

The mean fish-collecting efficiency for the electrode array and array trap with the power on was highest at a water velocity of 0.2 m.p.s.; intermediate at 0.8 m.p.s.; and lowest at 0.5 m.p.s. (fig.

TABLE 3.—*Fish-collecting efficiency (in percent) of the electrode array and array trap, with the electrode array energized, for each water velocity, test period, and fish species*

Velocity	Test period	Species		
		Chinook salmon	Coho salmon	Rainbow-steelhead trout
M.p.s.		*Percent*	*Percent*	*Percent*
0.2	1	88.2	82.0	71.3
	2	81.2	82.8	74.3
	3	78.2	86.0	75.9
	4	93.9	82.0	64.1
	Average	85.4	83.2	71.4
.5	1	77.1	77.9	43.3
	2	79.7	82.3	64.2
	3	72.6	60.5	59.8
	4	39.9	24.6	28.9
	Average	67.3	61.3	49.0
.8	1	88.2	76.2	74.9
	2	87.5	75.5	70.2
	3	86.4	76.1	72.2
	4	57.3	59.4	49.5
	Average	79.8	71.8	66.7

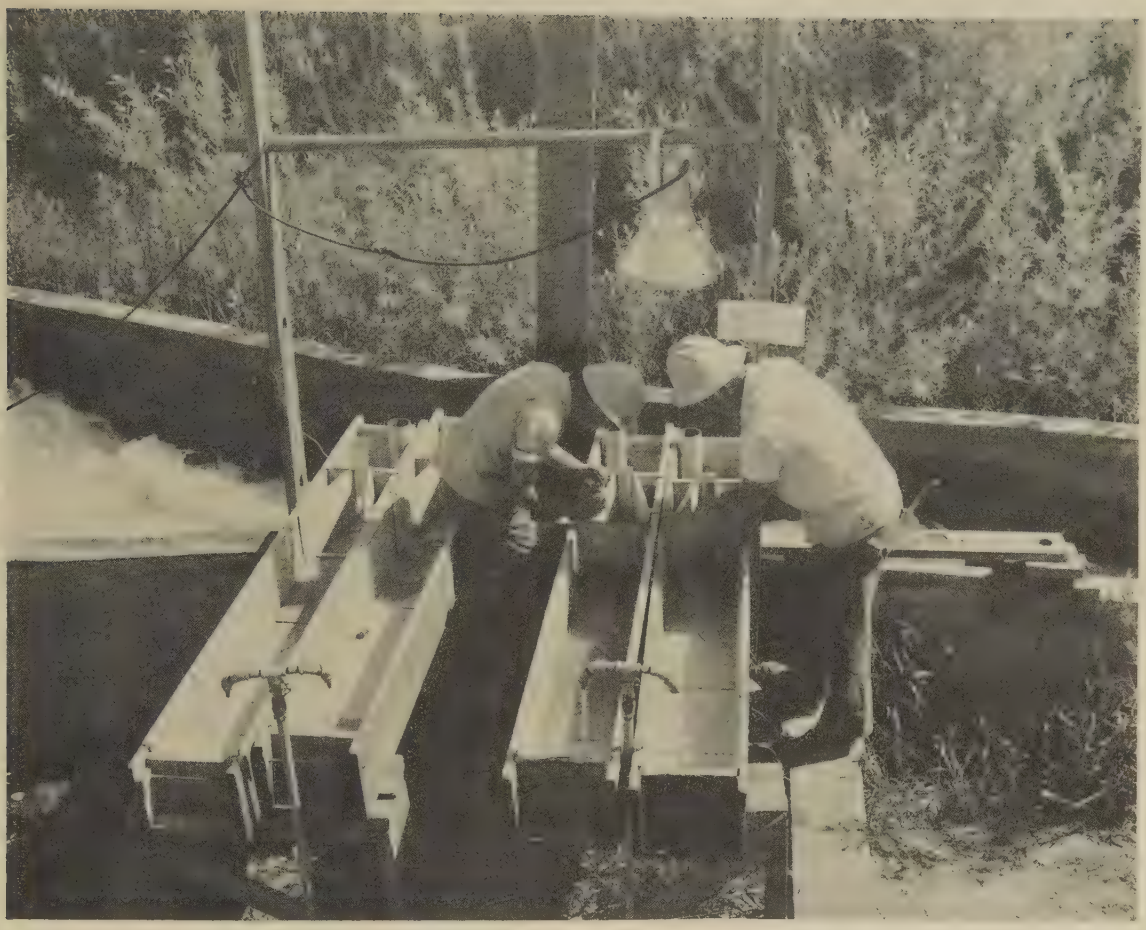

FIGURE 13.—Troughs for counting and identifying salmon and trout.

14). The decrease in fish-collecting efficiency between 0.2 and 0.5 m.p.s. and the increase at 0.8 m.p.s. suggests that fish-guiding efficiency decreased as the water velocity increased, but that perhaps: (1) the electrodes created hydraulic conditions that diverted more fish into the array trap at a water velocity of 0.8 m.p.s. than at 0.5 m.p.s. or (2) that the fish-holding efficiency of the array trap was higher at 0.8 m.p.s. than at 0.5 m.p.s. It was not possible within the scope of this research to determine the effect of the hydraulic conditions created by the electrodes on the fish-guiding efficiency of the electrical system, nor was it possible to determine conclusively the holding efficiency of the array trap at each of the three test velocities. Because salmon and trout populations of the Yakima River at the time of this experiment were so critically low, we deemed it inadvisable to handle, mark, and delay the number of migrating salmon and trout required to determine accurately the efficiency of the array trap in retaining fish.

General observations, however, indicated that fish could escape from the array trap at all test velocities but that fish-holding efficiency was higher at 0.5 m.p.s. and at 0.8 m.p.s. than at 0.2 m.p.s. Therefore, during the power-on tests, some fish were probably guided into the array trap by the electrical system but, because they were not removed immediately, they were able to escape by swimming back upstream into the canal. Consequently, all of the fish-guiding and collecting efficiencies reported here for the low and middle water velocities are probably lower than the actual efficiencies achieved. Those reported for the highest water velocity, 0.8 m.p.s., are probably more accurate than those for the lower velocities, but even these values are doubtless below the actual values achieved.

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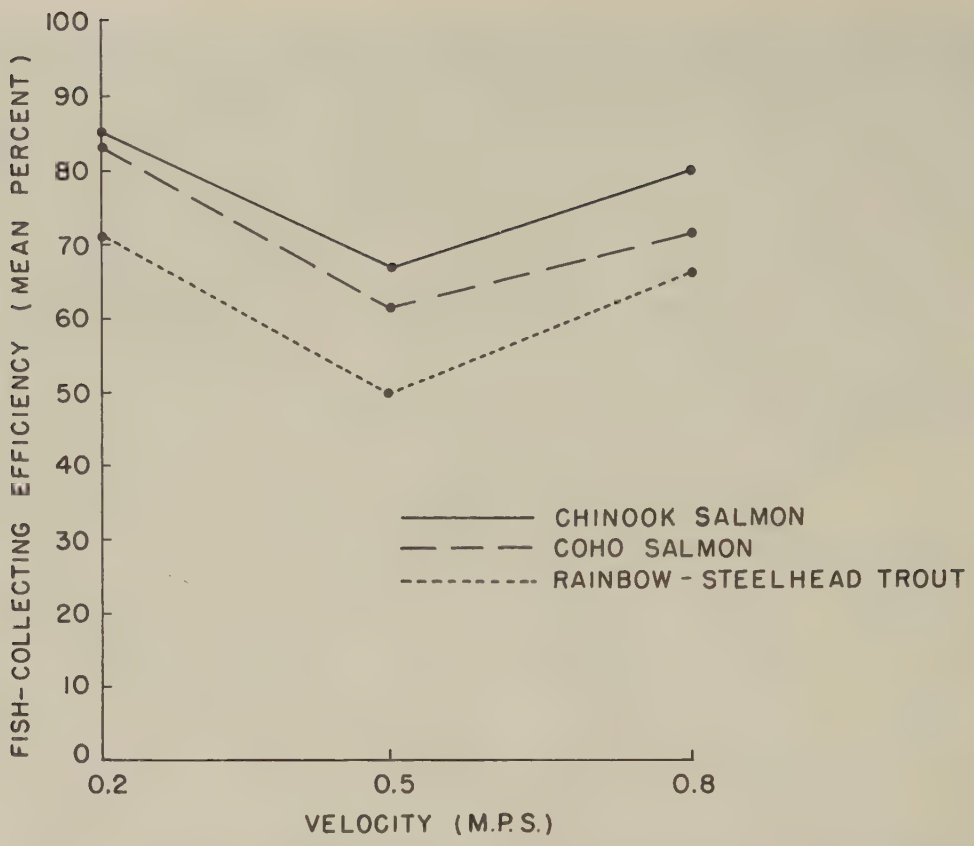

FIGURE 14.—Fish-collecting efficiency (mean percent) of the electrode array and array trap, with the electrode array energized, for each water velocity and fish species.

Figure 14 shows that the mean fish-collecting efficiency was highest for chinook salmon, intermediate for coho salmon, and lowest for rainbow-steelhead trout.

Examination of table 3 shows that at the 0.2 m.p.s. velocity, the results were about the same in the fourth test period as in the first three. At the middle and high water velocities, however, the fish-guiding and collecting efficiencies were substantially lower during the fourth test period than during the first three. To determine the reason for this decrease, we considered such factors as the size of fish, timing in the migration period, environmental fluctuations, possible malfunctions of the electronic equipment, and underwater damage to the electrode array trap. None of these factors, however, were sufficiently different from previous conditions to provide an explanation for the lower fish-guiding efficiencies. (It should be noted that the sudden unexplained failures in fish guidance at the middle and high water velocities did not occur at 0.2 m.p.s., which was the last velocity tested during the fourth test period—see table 2.)

ELECTRODE ARRAY NONENERGIZED PLUS ARRAY TRAP

We calculated the fish-collecting efficiency of the electrode array and array trap with the power off (table 4) for each test velocity and test period, by fish species, by the same method used to determine the fish-collecting efficiency of the electrode array and array trap with the power on. The catches compared were those made under control conditions. Figure 15 shows that the fish-collecting efficiency (mean percent) of the electrode array and array trap with the power off increased for all three species as the velocity increased. This increase in fish-collecting efficiency with increasing velocity during tests with the power off substantiates one or both of our previous hypotheses that: (1) the electrodes created hydraulic conditions at the higher water velocities that diverted fish into

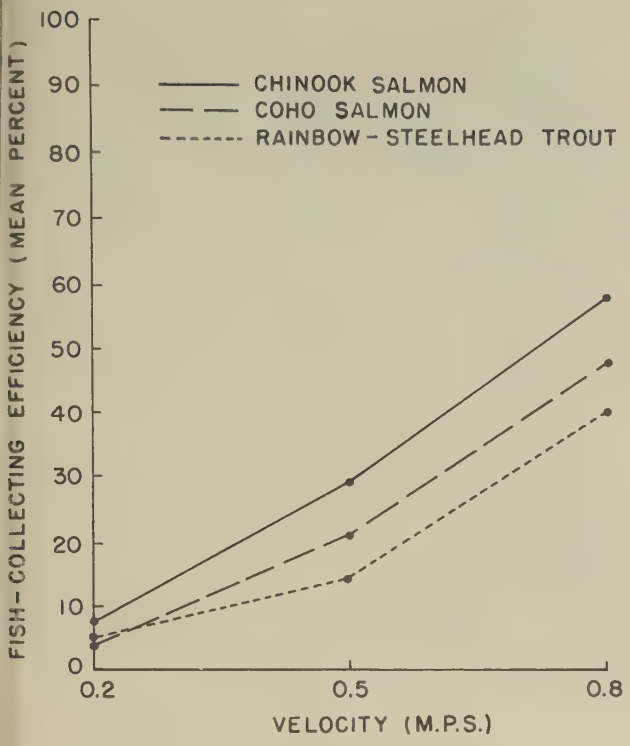

FIGURE 15.—Fish-collecting efficiency (mean percent) of the electrode array and array trap during the control conditions (power off) for each water velocity and fish species.

the array trap or (2) the fish-holding efficiency of the array trap increased with increased water velocity. In general, the rank of the species in relation to fish-collecting efficiency of the electrode array and array trap was the same as during the power-on test; chinook salmon ranked first, coho salmon second, and rainbow-steelhead trout third.

TABLE 4.—*Fish-collecting efficiency (in percent) of the electrode array and array trap during the control conditions (power off) for each water velocity, test period, and fish species*

Velocity	Time period	Species		
		Chinook salmon	Coho salmon	Rainbow-steelhead trout
M.p.s.		*Percent*	*Percent*	*Percent*
0.2	1	6.6	2.4	4.4
	2	10.5	10.2	12.3
	3	5.0	3.7	2.1
	4	5.7	2.8	1.3
	Average	7.0	4.8	5.0
.5	1	29.2	45.0	16.5
	2	30.2	23.6	14.1
	3	23.8	19.1	6.2
	4	30.0	22.0	18.0
	Average	28.3	27.4	13.7
.8	1	58.5	70.5	47.3
	2	56.8	45.2	44.6
	3	64.8	44.2	39.6
	4	58.6	33.0	31.3
	Average	59.7	48.2	40.7

ELECTRODE ARRAY ENERGIZED WITHOUT ARRAY TRAP

Fish-guiding efficiency of the electrode array (power on), without the array trap, is presented in table 5 as percentage differences between the fish-guiding and collecting efficiency of the electrode array and array trap with the power on and the efficiency with the power off. Table 5, however, is only an indication of the actual fish-guiding efficiency of the electrical guiding system. As previously mentioned, fish swimming more than 0.9 to 1.2 m. from the electrodes were not visibly affected by the electrical field created by the electrode array. As the entrance to the array trap was 6.4 m. wide, it was possible for fish migrating near the middle of the experimental canal (i.e., near the middle of the trap entrance) to enter the array trap without having been diverted by the electrical energy. These fish, therefore, were not actually available to be guided by the electrical system. Assuming that the same percentage of fish entered the array trap naturally (i.e., without being guided) during the power-on conditions as during the control periods, we established the following relations to determine the actual fish-guiding efficiency of the electrical system alone:

Let AT_p = Total number of fish captured in the array trap on any given power-on day.

IST_p = Total number of fish captured in the inclined-screen trap on the same power-on day.

AT_o = Total number of fish captured in the array trap on the preceding power-off day.

IST_o = Total number of fish captured in the inclined-screen trap on the same power-off day.

P_E = Percentage of fish guided by the electrical system that were actually available to be guided; i.e., fish that would not have entered the array trap naturally.

Then
$$P_E = \frac{AT_p - \left[\frac{(AT_o)}{(AT_o+IST_o)}(AT_p+IST_p)\right]}{IST_p - \left[\frac{(AT_o)}{(AT_o+IST_o)}(AT_p+IST_p)\right]} \times 100$$

TABLE 5.—*Fish-guiding efficiency (in percent) of the electrode array (power on), without the array trap, for each water velocity, test period, and fish species; values were determined by subtracting percentage of fish collected with the power off from percentage guided with the power on*

Velocity	Time period	Species		
		Chinook salmon	Coho salmon	Rainbow-steelhead trout
M.p.s.		*Percent*	*Percent*	*Percent*
0.2	1	81.6	79.6	67.0
	2	70.7	72.7	62.0
	3	73.1	82.3	74.0
	4	88.3	79.2	63.0
	Average	78.4	78.5	66.5
.5	1	47.9	32.9	27.0
	2	49.5	58.7	50.2
	3	48.7	41.4	54.0
	4	10.0	2.6	11.0
	Average	39.0	33.9	35.6
.8	1	29.6	5.7	27.6
	2	30.7	30.3	25.6
	3	21.6	31.9	32.6
	4	−1.3	26.4	18.2
	Average	20.2	23.6	26.0

Table 6 was prepared from the above formula and shows, by fish species, the adjusted fish-guiding efficiency of the electrical system for each experimental condition. Figure 16 shows the mean percentage fish-guiding efficiency of the electrode array (power on), without the array trap, for each test velocity and species. In general, efficiency was inversely related to velocity—it was highest at 0.2 m.p.s., second highest at 0.5 m.p.s., and lowest at 0.8 m.p.s. Mean guiding efficiency by species was highest for chinook salmon, intermediate for coho salmon, and usually lowest for rainbow-steelhead trout.

QUALIFICATIONS OF COMPUTATION METHODS

Because the inclined-screen trap was several hundred meters downstream from the array trap, a slight delay existed between the time that fish of a particular school or group entered the array trap and the remainder of that school or group entered

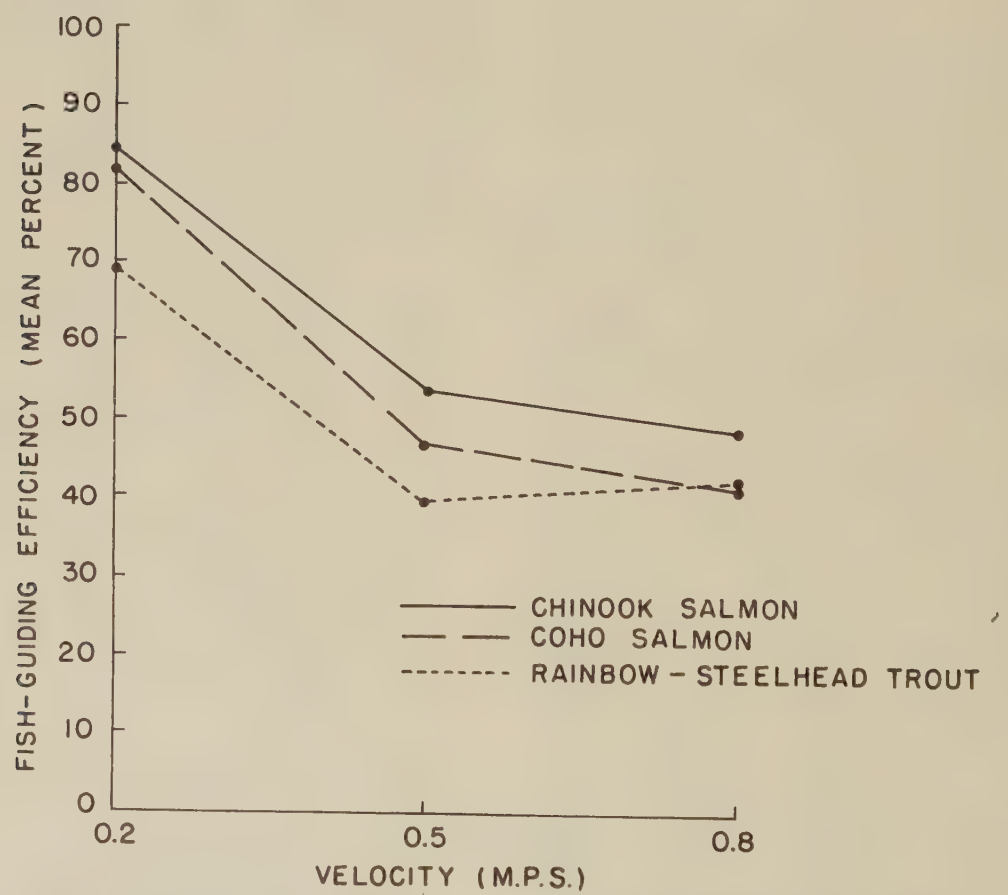

FIGURE 16.—Fish-guiding efficiency (mean percent) of the electrode array (power on), without the array trap, for each water velocity and fish species.

the inclined-screen trap. Tests to determine the exact time involved in this delay were not conclusive but indicated that the delay was usually less than 4 hours and often even less than 1. Although the array trap was checked every 2 hours and the inclined-screen trap every 4, we computed the fish-guiding and collecting efficiencies by grouping the fish captured in each trap during a 24-hour period and then comparing these totals.

TABLE 6.—*Adjusted fish-guiding efficiency (in percent) of the electrode array (power on), without the array trap, for each water velocity, test period, and fish species*

Velocity	Time period	Species		
		Chinook salmon	Coho salmon	Rainbow-steelhead trout
M.p.s.		*Percent*	*Percent*	*Percent*
0.2	1	87.4	81.5	70.0
	2	79.0	80.9	70.7
	3	77.0	85.4	75.4
	4	93.6	81.5	63.6
	Average	84.2	82.4	69.9
.5	1	67.7	59.8	32.0
	2	70.9	76.8	58.4
	3	64.0	51.2	57.1
	4	14.3	3.4	13.3
	Average	54.2	47.8	40.2
.8	1	71.5	19.2	52.4
	2	71.1	55.3	46.2
	3	61.3	57.1	54.0
	4	−3.1	39.4	26.5
	Average	50.2	42.8	44.8

Consequently, the delay time due to the distance between the two traps affected only the data for the last inclined-screen trap catch in each 24-hour period. Therefore, no lag time was allowed in computing any of the fish-collecting efficiencies. The total number of fish captured in the array trap from 12:00 midnight to the following 12:00 midnight was compared with the total number of fish captured in the inclined-screen trap during the same period. When we analyzed the data to allow for a 4-hour delay (comparing catches in the array trap between 12:00 midnight and the following 12:00 midnight with catches in the inclined-screen trap between 4:00 a.m. and the following 4:00 a.m.) and an 8-hour delay (comparing catches in the array trap between 12:00 midnight and the following 12:00 midnight with catches in the inclined-screen trap between 8:00 a.m. and the following 8:00 a.m.), the results did not modify our major conclusions.

CONCLUSIONS

We have two major conclusions:

1. The fish-guiding efficiency of the electrical system generally decreased as water velocity increased, probably because juvenile salmon and trout may be progressively less able to control their movements as velocity increases.

2. The use of electricity to guide juvenile salmon and trout migrating downstream may be feasible in certain environments where the water velocity does not exceed 0.3 m.p.s., but does not appear practical for use in most rivers and streams.

ACKNOWLEDGMENTS

The Bureau of Reclamation allowed us to use the Chandler Canal near Prosser, Wash., as our experimental site. The Washington State Departments of Fisheries and Game cooperated by permitting us to experiment on natural, downstream migrating fish of the Yakima River system. Winston Farr designed the velocity control and fish-capturing facilities, and Holbrook L. Garrett designed and supervised the construction of the electrode array. William S. Davis, Jr., planned the experimental design, and Charles C. Gillaspie constructed the electrical equipment and was responsible for its operation and maintenance.

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REVISION OF THE GENUS *SYMPHYSANODON* (PISCES: LUTJANIDAE) WITH DESCRIPTIONS OF FOUR NEW SPECIES[1]

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ABSTRACT

The genus is redescribed; four new species — two from the western Atlantic and two from the Pacific — are described; *S. typus,* from the Pacific and until recently the only known species of the genus, is redescribed; and a key to the species is provided. Discussions are presented on the systematic position of the genus, the synonymies of species, and the zoogeography and phylogeny of the genus; species are compared; and brief comments are made on distributions.

Two new species of *Symphysanodon* (Pisces: Lutjanidæ) have been collected in the West Indies and Caribbean Sea during cruises of the research vessels *Combat, Oregon, Silver Bay,* and *Undaunted* of the FWS (U.S. Fish and Wildlife Service) and the *Gerda* and *John Elliott Pillsbury* of the Institute of Marine Sciences, University of Miami. A third new species has been collected off Hawaii—off a lava flow by William A. Gosline and coworkers and during cruises of the FWS research vessel *Townsend Cromwell* by Paul J. Struhsaker. A fourth new species has been obtained off Japan by students of Kochi University. Until the discovery of the Atlantic species, this genus was known only from the Kai Islands, New Guinea, the Philippines, Japan, and Hawaii. Three scientific names have been proposed for Pacific *Symphysanodon;* this study shows that all three apply to the same species (*S. typus*). Anderson (1967) mentioned two undescribed species of *Symphysanodon* from the western Atlantic and presented a key for their separation; they are described herein.

The following abbreviations are used: AM, The Australian Museum (Sydney); AMNH, The American Museum of Natural History; ANSP, The Academy of Natural Sciences of Philadelphia; BLBG, BCF (Bureau of Commercial Fisheries) Biological Laboratory (Brunswick, Ga.); BPBM, Bernice P. Bishop Museum (Honolulu, Hawaii); BMNH, British Museum (Natural History); BOC, Bingham Oceanographic Collections, Yale University; CU, Cornell University; FMNH, Field Museum of Natural History (Chicago, Ill.); HBL, BCF Biological Laboratory (Honolulu, Hawaii); IRSNB, Institut Royal des Sciences Naturelles de Belgique (Brussels); LACM, Los Angeles County Museum of Natural History; MCZ, Museum of Comparative Zoology, Harvard University; MNHN, Museum National d'Histoire Naturelle (Paris, France); RMNH, Rijksmuseum van Natuurlijke Historie (Leiden, Netherlands); SU, Stanford University; TABL, BCF Tropical Atlantic Biological Laboratory (Miami, Fla.); TU, Tulane University; UF, Florida State Museum, University of Florida; UH, University of Hawaii; UMML, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami; UMMZ, Museum of Zoology, The University of Michigan; USNM, U.S. National Museum; UW, College of Fisheries, University of Washington; YU, Yamaguchi University (Yamaguchi City, Japan); ZIKU, Zoological Institute, Kochi University (Kochi, Japan); and ZSZM, Zoologisches Staatsinstitut und Zoologisches Museum (Hamburg, West German Federal Republic). SL designates standard length.

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METHODS

Measurements and counts were made according to the methods of Hubbs and Lagler (1958), except for the following: depth of head was measured just posterior to orbit; length of orbit, as longest horizontal distance between fleshy margins of orbit; width of bony interorbital, above vertical midline of eye; depth of body, from origin of first dorsal spine vertically to ventral surface of body; and lengths of caudal fin lobes, from middle of origin of caudal fin to distal ends of longest rays. The last ray of dorsal and anal fins was counted as one when branched to the base.

Pelvic fins and caudal-fin lobes with long filaments were difficult to measure. Some of the filamentous fins were measured by stretching them out along a meter stick. Other measurements were made with needlepoint-micrometer-dial calipers. When the two pectoral and two pelvic fins were of unequal length, the longer fin was measured.

Where possible, gill rakers (including rudiments, when present) on the anterior gill arch and pectoral-fin rays were counted on the right side, pored lateral-line scales on the left side.

Most specimens had lost many scales and consequently accurate counts of pored lateral-line scales were made on fewer than a third of those examined. Approximate counts of lateral-line scales were recorded for a number of specimens. Accurate and approximate counts of scales are combined in table 1 and distinguished in table 2.

GENUS *SYMPHYSANODON* BLEEKER

Symphysanodon Bleeker, 1878: 60—also p. 26 in author's undated reprint—(type species *Symphysanodon typus* Bleeker, 1878, by original designation—by virtue of the name *typus*).

Propoma Günther, 1880: 39 (type species *Propoma roseum* Günther, 1880 [= *Symphysanodon typus* Bleeker, 1878], by monotypy).

Rhyacanthias Jordan, 1921: 646 (type species *Rhyacanthias carlsmithi* Jordan, 1921 [= *Symphysanodon typus* Bleeker, 1878], by original designation).

Snout relatively blunt. Anterior ends of premaxillaries incised, forming a conspicuous notch —the notch receiving the anterior ends of the dentaries. Extreme dorsalmost margin of maxillary covered by very narrow suborbital with mouth closed. Mouth terminal; mandible inclined dorsally when mouth closed; jaws about equal. A bony elevation (which may be pronounced) on posterodorsal surface of dentary. Two narial openings on each side. Pseudobranchiæ present. Gill arches four, a slit behind the fourth. Premaxillary with small teeth—usually larger anteriorly; premaxillary notch toothless. Dentary with small teeth usually extending from bony elevation almost to the symphysis; teeth on and near bony elevation usually larger; usually a number of relatively large, exserted teeth at anterior end of dentary—these teeth fitting into notch in upper jaw when mouth closed; symphysis toothless. Teeth, when present, on vomer, palatines, and pterygoids small; no teeth on tongue. Dorsal fin continuous and not incised at junction of spines and soft rays. Opercle with two flattened spines, the ventral one longer and more prominent. Scales ctenoid; posterior part of snout, interorbital, preorbital, suborbital, maxillary, ventral surface of mandible, preopercle, interopercle, opercle, and subopercle with scales; dorsal and anal fins without scales, but with scaly sheaths at their bases; large modified scales associated with pelvic fins, just dorsal to each pelvic spine (axillary scales) and in the ventral midline between the pelvic fins somewhat overlapping their anteromedial borders. Lateral line gently curved beneath the dorsal fin; cephalic lateral-line system well developed. Pronounced sexual dimorphism in at least one species (and probably in two).

Dorsal-fin rays usually IX, 10. Anal-fin rays III, 7 or 8. Pectoral-fin rays 15 to 18. Pelvic-fin rays I, 5. Principal caudal-fin rays 17 (9 + 8). Vertebrae 25 (10 precaudal + 15 caudal). Branchiostegal rays 7. Gill rakers well developed, rather long and slender, 9 to 14 + 22 to 29—total on anterior gill arch 31 to 42. Pored lateral-line scales 43 to 54.

SYSTEMATIC POSITION OF THE GENUS *SYMPHYSANODON*

Symphysanodon, which has been variously considered as a serranid or as a lutjanid, superficially resembles the members of the serranid subfamily Anthiinæ and is unlike (in at least its superficial appearance) the more generalized lutjanids, such as *Lutjanus* and its allies. Kamohara and Katayama (1959) placed *Symphysanodon* in the subfamily Anthiinæ of the Serranidæ; Katayama (1960) placed it in the Serranidæ, but did not refer it to a subfamily. Gosline and Brock (1960) and Munro (1967) included this genus with the Lutjanidæ.

Gosline (1966) provisionally combined a number of serranid subfamilies (sensu Katayama, 1960) along with certain genera (such as *Roccus* and *Percichthys*) into the family Percichthyidæ, but retained the subfamily Anthiinæ (sensu Katayama, 1960) in the Serranidæ. He excluded *Symphysanodon* from the Serranidæ, but did not allocate it to a family. Gosline did note, however, that *Symphysanodon* shows a closer resemblance to lutjanids than to serranids in fin-ray counts and in the possession of parietal crests and well-developed axillary scales associated with the pelvic fins.

On the basis of a number of osteological characters Katayama (1968) stated that *Symphysanodon* resembles the Percichthyidæ (of Gosline, 1966) more than the Serranidæ (as restricted by Gosline, 1966). Katayama (1968) mentioned that *Symphysanodon* differs from the Lutjanidæ in the myodome not opening to the exterior through a foramen, in the sensory canal of the frontal bone lacking an inner branch connecting with the corresponding one of the opposite side, in having an oblong foramen near the upper margin of the ceratohyal, and in having 25 vertebrae. (Most Lutjanidæ have 24 vertebrae. According to Gosline (1966), the Percichthyidæ have 25 vertebrae—frequently more, members of the Anthiinæ tend to have 26, and the other subfamilies of the Serranidæ— the Epinephelinæ and the Serraninæ—have 24.) Katayama (1968) also listed a number of osteological structures of *Symphysanodon* which are more similar morphologically to the corresponding structures of the Lutjanidæ than to those of the Percichthyidæ. These structures are: jaw bones, suspensorium and opercular apparatus, pectoral girdle, and pelvic girdle. In addition, he noted that *Symphysanodon* is closer to the Lutjanidæ (than to the Percichthyidæ) in possessing fronto-parietal crests and axillary scales associated with the pelvic fins. In concluding his paper on *Symphysanodon,* Katayama (1968) remarked that he ". . . would like to place *Symphysanodon typus* Bleeker under Lutjanidæ . . ." and that this genus seems to be closely related to the members of the subfamily Etelinæ.

On the basis of the studies by Gosline (1966) and Katayama (1968) and my own investigations, I assign *Symphysanodon* to the Lutjanidæ (in which its greatest affinities are with the Etelinæ).

KEY TO THE SPECIES OF *SYMPHYSANODON*

Gill-raker counts are of the total number on the anterior gill arch (including rudiments, when present); scale counts are of the number of pored lateral-line scales on the body (excluding those posterior to the caudal base); gill-raker and scale counts of individual specimens appear to be correlated (see table 1).

A. Depth of body 2.8 to 3.0 times in SL (33.4–36.0 percent SL). Anal soft rays usually 8 (7 in about 10 percent of specimens examined). Gill rakers 39 to 42. Scales 45 or 46 ..... *octoactinus,* western Atlantic.

TABLE 1.—*Relation of total number of gill rakers on anterior gill arch to number of pored lateral-line scales in* Symphysanodon

[t = *S. typus;* k = *S. katayamai;* m = *S. maunaloae;* b = *S. berryi;* o = *S. octoactinus;* numbers within the body of the table represent the individuals with each gill raker-scale combination]

Total gill rakers	43	44	45	46	47	48	49	50	51	52	53	54
42				o1								
41			o3									
40				o1								t1
39			o1				b1	b1				
38						b2	b2		b1	b1	t1	t1
37				m1		b1	b2	b8		t2	t1	
36	m1					b6	b6	b1	b1			
35						b1	b4	k1 b5	b2			
34			m1	m2	m1		b2	b1				
33	m1		m1	m2	m3							
32		m1	m1	m1	m1							
31			m1									

Lateral-line scales

AA. Depth of body 3.2 to 4.7 times in SL (21.3–ca. 31 percent SL). Anal soft rays 7. Gill rakers 31 to 40. Scales 43 to 54 ..... B

B. Anal fin long, length of depressed anal fin 2.6 times in SL (ca. 39 percent SL). Depth of body 3.2 times in SL (ca. 31 percent SL) ..... *katayamai*, Japan.

BB. Anal fin short, length of depressed anal fin 3.1 to 4.4 times in SL (22.8–32.6 percent SL). Depth of body 3.4 to 4.7 times in SL (21.3–29.0 percent SL) C

C. Scales 43 to 47. Gill rakers 31 to 37. Sum of gill rakers plus scales 76 to 81, 83 ..... *maunaloæ*, Hawaii.

CC. Scales 48 to 54. Gill rakers 34 to 40. Sum of gill rakers plus scales 83 to 92, 94 ..... D

D. Scales 48 to 51 (rarely 52). Gill rakers 34 to 39. Pectoral-fin rays 16 to 18, usually 17. Vertical limb of preopercle usually with well-developed serrae at all sizes; usually a single spine (most frequently serrate, often bifid) or spinelike process at angle of preopercle. First pelvic soft ray noticeably produced in males larger than ca. 85 mm. SL, extremely filamentous in large males. Caudal-fin lobes frequently produced into excessively long filaments in large males ..... *berryi*, western Atlantic.

DD. Scales 52 to 54. Gill rakers 36 to 38, 40. Pectoral-fin rays 15 to 17, usually 16. Vertical limb of preopercle with small serrae in small specimens (80 mm. SL or smaller), finely serrate, slightly roughened, or almost smooth in specimens larger than 100 mm. SL; usually a well-developed spine at angle of preopercle in specimens 80 mm. SL or smaller, spine or spinelike process present or absent in specimens larger than 100 mm. SL. First pelvic soft ray only slightly produced, not extending to anal fin. Caudal-fin lobes produced, but apparently never produced into excessively long filaments ..... *typus*, New Guinea, Kai Islands, Philippine Islands, and Hawaii.

KEY TO *SYMPHYSANODON BERRYI* AND *S. TYPUS*

Measurements of certain body parts can be used to distinguish specimens of *S. berryi* and *S. typus* of similar sizes. Because I had no specimens of *S. typus* between 80 and 100 mm. SL, that size range is excluded in the following key.

A. Specimens 80 mm. SL or smaller ..... B

AA. Specimens larger than 100 mm. SL C

B. Length of depressed anal fin 22.8 to 25.8 percent SL. First anal spine 3.3 to 5.2 percent SL (usually 3.9–4.9). Length of base of anal fin 12.7 to 15.3 percent SL (usually 13.0–14.9) ..... *berryi*.

BB. Length of depressed anal fin 27.7 to 30.2 percent SL. First anal spine 5.0 to 6.2 percent SL. Length of base of anal fin 14.7 to 16.4 percent SL ..... *typus*.

C. Length of third anal spine 12.5 to 15.0 percent SL (usually 12.7–14.6). Length of second anal spine 10.6 to 13.4 percent SL (usually 10.9–13.0). Length of first anal spine 3.4 to 5.6 percent SL (usually 3.9–5.1). Length of base of anal fin 13.4 to 15.8 percent SL (usually 13.6–15.3). Length of depressed anal fin 23.4 to ca. 27.6 percent SL (usually 24.0–26.2) ..... *berryi*.

CC. Length of third anal spine 10.8 to 12.0 percent SL. Length of second anal spine 10.0 to 10.5 percent SL. Length of first anal spine 5.4 to 6.1 percent SL. Length of base of anal fin 15.6 to 20.8 percent SL. Length of depressed anal fin 26.6 to 32.6 percent SL ..... *typus*.

SYMPHYSANODON TYPUS BLEEKER

Figure 1; tables 1 to 4

Symphysanodon typus Bleeker, 1878: 61, pl. 3, fig. 1—also p. 27, pl. 2, fig. 1, in author's undated reprint—(original description and illustration; holotype ZSZM H 398, 112 mm. SL; type locality New Guinea). ..... Bleeker, 1880: 28, pl. 5, fig. 2 (description apparently based on same material as that of Bleeker, 1878, and illustration; New Guinea). ..... Jordan and Seale, 1906: 268 (reference to original description). ..... Weber and de Beaufort, 1936: 309, fig. 65 (synonymy referring in part to *S. typus* and in part to *S. maunaloæ*, compiled description [probably representing *S. typus*], illustration [after Günther, 1880], and distribution referring to *S. typus* and in part to *S. maunaloæ*). ..... Tinker,

FIGURE 1.—Holotype of *Symphysanodon typus* (ZSZM H 398), 112 mm. SL.

1944: 200, fig. (illustration [drawn from Jordan and Jordan, 1922]; notes on color, size, and distribution [based on ?]). ------- Ladiges, von Wahlert, and Mohr, 1958: 163 (listing of ZSZM H 398 from New Guinea as lectotype of *S. typus*, herein considered as an attempt to designate this specimen as the lectotype of *S. typus;* indication that ZSZM H 398 may be holotype of *S. typus*). ..... Munro, 1958: 192 (reference to original description). ..... Gosline and Brock, 1960: 183–184, 327 (at least in part; partial synonymy; characters which can be used to identify *Symphysanodon;* Hawaii). ..... Anderson, 1967: 2, 11 (compiled meristic data referring in part to *S. typus*, in part to *S. maunaloæ*, and in part to *S. katayamai;* distribution referring in part to *S. typus*, in part to *S. maunaloæ*, and in part to *S. katayamai*). ..... Munro, 1967: 288 (characters which can be used to identify *Symphysanodon;* note that *S. typus* has been recorded from west New Guinea).

Propoma roseum Günther, 1880: 39, pl. 20, fig. B (original description and illustration; lectotype, herein designated, BMNH 1879.5.14.164–5, 107 mm. SL; type locality off Kai Islands). ..... Fowler, 1925: 39 (remarks concerning familial position of *Propoma roseum* Günther and similarity of *P. roseum* to *Rhyacanthias carlsmithi* Jordan).

Rhyacanthias carlsmithi Jordan, 1921: 647, fig. 3 (original description and illustration; holotype USNM 84099, ca. 148 mm. SL; type locality off a lava flow from Mauna Loa, Alika, Kau District, Hawaii). ..... Jordan and Jordan, 1922: 46, fig. 3 (reference to original description, illustration [after Jordan, 1921], and locality of collection). ..... Fowler, 1925: 39 (mention of similarity to *Propoma roseum* Günther).

Symphysodon typus, Herre, 1950: 151 (lapsus calami for *Symphysanodon;* synonymy; description of six specimens taken off the Philippines).

DIAGNOSIS

Body slender, the depth 22.1 to 29.0 percent SL. First pelvic soft ray only slightly produced, not extending to anal fin. Anal fin short, length of depressed anal fin 26.6 to 32.6 percent SL. Caudal fin deeply forked, both lobes produced, but apparently never produced into excessively long filaments. Anal soft rays 7. Gill rakers 10 to 12 + 25 to 28—total 36 to 38, 40. Pored lateral-line scales 52 to 54.

DESCRIPTION

Maxillary extending posteriorly to about middle of eye or slightly beyond. Length of upper jaw contained in length of mandible 0.95 to 1.08 times. Interorbital region flattened. Small teeth present on vomer (in a small patch), palatines (in a single band on each), and mesopterygoids (in patches) of two largest specimens (ca. 148 and 165 mm. SL)—teeth, if present, on ectopterygoids of two largest specimens confined to anterior tip of bone; teeth not apparent on vomer, palatines,

mesopterygoids, and ectopterygoids of other specimens (50–112 mm. SL). Vertical limb of preopercle with fine serrae in small specimens (80 mm. SL or smaller), finely serrate, slightly roughened, or almost smooth in specimens more than 100 mm. SL; horizontal limb of preopercle smooth or almost smooth; usually a well-developed spine at angle of preopercle in specimens 80 mm. SL or smaller, spine or spinelike process present or absent in specimens more than 100 mm. SL. Anterior part of snout and most of gular region without scales; usually one to several scales present in midline of anterior part of gular region; largest specimen examined (165 mm. SL) with a few scales on the membrane covering the fourth branchiostegal ray on each side (no other scales seen on branchiostegal membranes of this specimen), no scales apparent on branchiostegal membranes of other specimens.

Counts

Frequency distributions for the following counts are given in tables 2, 3, and 4. Dorsal-fin rays IX, 10. Anal-fin rays III, 7. Pectoral-fin rays 15 to 17. Gill rakers 10 to 12 + 25 to 28—total 36 to 38, 40. Pored lateral-line scales 52 to 54. Sum of total number of gill rakers on anterior gill arch plus number of pored lateral-line scales of individual specimens 89 to 92, 94.

(The holotype of *Rhyacanthias carlsmithi*, USNM 84099, is a dried specimen, ca. 148 mm. SL. Because the dorsal- and pectoral-fin rays and gill rakers were not counted with certainty on this specimen, data for these counts are omitted from tables 3 and 4.)

TABLE 2.—*Frequency distributions of number of pored lateral-line scales in* Symphysanodon

[The upper number in a block represents accurate counts, the lower number approximate counts]

Species	43	44	45	46	47	48	49	50	51	52	53	54	$\bar{X}$
typus	..	..	..	..	..	..	..	..	..	2	2	1	52.80
	..	..	..	..	..	..	..	..	..	1*	.	1	53.00
katayamai	..	..	..	..	..	..	..	1*	..	..	..	..	50.00
	..	..	..	..	..	..	..	..	..	..	..	..	....
maunaloae	2	..	4*	4	3	..	..	..	..	..	..	..	45.46
	..	1	..	2	2	..	..	..	..	..	..	..	46.00
berryi	..	..	..	..	..	7	10	10*	4	1	.	..	49.44
	..	..	..	..	..	3	7	6	.	.	.	..	49.19
octoactinus	..	..	3	2*	..	..	..	..	..	..	..	..	45.40
	..	..	1	..	..	..	..	..	..	..	..	..	45.00

*Includes holotype.

Measurements

Ranges of selected measurements are presented in percentage of standard length followed by the value for the holotype of *S. typus* in parentheses. For some characters variation with size is indicated. Length of head 27.7 to 33.5 (32.0)—32.2 to 33.5 in specimens 50 to 80 mm. SL, 27.7 to 32.2 in those of 105 to 165 mm. SL. Depth of head 19.1 to 24.2 (21.0)—19.1 to 21.9 in specimens 50 to 80 mm. SL, 21.0 to 24.2 in those

TABLE 3.—*Frequency distributions of numbers of fin rays in* Symphysanodon

Species	Dorsal-fin rays				Anal-fin rays		Pectoral-fin rays				
	VIII,11	IX,9	IX,10	X,10	III,7	III,8	15	16	17	18	$\bar{X}$
typus			11*	....	12*	..	1	7*	2	..	16.10
katayamai			1*	....	1*	.....		1*	.....		16.00
maunaloae		3	23*	....	26*	..	3	19*	4	..	16.04
berryi	1	1	132*	....	134*	.....		12	107*	15	17.02
octoactinus		1	17*	1	2	17*	..	18*	1	..	16.05

*Includes holotype.

TABLE 4.—*Frequency distributions of number of gill rakers in* Symphysanodon

Species	Upper limb							Lower limb									Total (= upper limb + lower limb)													
	9	10	11	12	13	14	$\bar{X}$	22	23	24	25	26	27	28	29	$\bar{X}$	31	32	33	34	35	36	37	38	39	40	41	42	$\bar{X}$
typus		2	6*	3	.....		11.09	.....			1	8*	1	1	..	26.18	.....					3	4*	3	....	1	.....		37.27
katayamai			1*	.....			11.00	.....		1*	.....					24.00	.....				1*	.....							35.00
maunaloae	4	19*	3	.....			9.96	4*	12	8	1	1	.....			23.35	1	5*	11	6	1	1	1	.....					33.31
berryi	1	69	61*	3	.....		10.49	.....		9	57	50*	17	1	..	25.58	.....			9	39	39	30*	14	3	.....			36.07
octoactinus		5	12*	2			12.84	.....			1	10*	6	2		27.47	.....								6	4*	6	3	40.32

*Includes holotype.

105 to 165 mm. SL. Length of snout 6.1 to 8.2 (ca. 6.2). Horizontal diameter of fleshy orbit 8.1 to 12.0 (11.0)—ca. 11.1 to 12.0 in specimens 50 to 80 mm. SL, 8.1 to 11.0 in those 105 to 165 mm. SL. Width of suborbital 0.7 to 1.3 (ca. 1.1). Height of cheek 4.2 to 6.2 (5.4). Length of upper jaw 12.4 to 15.0 (14.2). Length of mandible 12.5 to 14.6 (14.4). Width of bony interorbital 6.6 to 8.7 (8.7). Depth of body 22.1 to 29.0 (27.0)—22.1 to 26.5 in specimens 50 to 80 mm. SL, 26.7 to 29.0 in those 105 to 165 mm. SL. Least depth of caudal peduncle 9.9 to 12.1 (10.9)—9.9 to 10.7 in specimens of 50 to 80 mm. SL, ca. 10.6 to 12.1 in those 105 to 165 mm. SL. Pectoral fin usually reaching a vertical through base of first or second dorsal soft ray; length of longer pectoral fin ca. 25.8 to ca. 29.7 (broken). Pelvic fin not extending to anal fin, first pelvic soft ray not greatly produced; length of longer pelvic fin ca. 22.3 to 25.4 (broken). Length of base of anal fin 14.7 to 20.8 (15.9)—14.7 to 16.4 in specimens 50 to 80 mm. SL, 15.6 to 20.8 in those 105 to 165 mm. SL. Length of depressed anal fin 26.6 to 32.6 (broken)—27.7 to 30.2 in specimens 50 to 80 mm. SL, 26.6 to 32.6 in those 105 to 165 mm. SL. Lengths of dorsal spines: first 4.9 to 6.3 (—),[4] second 9.3 to 10.5 (—),[4] third 10.8 to 13.6 (—),[4] fourth 11.2 to 14.6 (—),[4] longest (fifth or sixth) 11.9 to 15.7 (13.2), last 11.2 to 13.4 (—).[4] Lengths of anal spines: first 5.0 to 6.2 (6.0), second 9.5 to >10.8 (10.5), third 10.8 to 13.1 (12.0)—12.3 to 13.1 in specimens 50 to 80 mm. SL, 10.8 to 12.0 in those 105 to 165 mm. SL. Caudal fin deeply forked, both lobes produced, but apparently never produced into excessively long filaments. Length of upper lobe of caudal fin ca. 36.5 to >42 (broken). Length of lower lobe of caudal fin ca. 35.8 to >48 (broken)—based on measurements of three specimens only.

Coloration

Several color descriptions of *Symphysanodon typus* have been published. Bleeker (1878 and 1880) stated ". . . colore corpore pinnisque dilute roseo; iride aurantiaco-flava; caudali lobo superiore apice macula lata fusca." Günther (1880) remarked "Apparently rose coloured during life; caudal fin yellowish. Lower parts silvery." Jordan (1921) observed "Color uniform whitish when received, probably rosy silvery in life, with no markings or shades anywhere." Herre (1950) stated "Our specimens were roseate in life, turning to dull reddish brown in preservative. Thinly sprinkled over the sides are black circular dots. The fins, evidently clear red in life, are colorless to palè tan." Gosline and Brock (1960), presumably describing *S. typus*, gave the color as plain greenish.

In alcohol, specimens more than 100 mm. SL are straw colored—with some individuals showing scattered flecks of dark pigment. Specimens 80 mm. SL or smaller are darker with considerable numbers of dark pigment spots—two rows of spots on dorsal surface of caudal peduncle, sides of body with numerous spots more or less arranged in rows, many lighter punctulations scattered among the more linearly arranged larger spots (this particularly evident dorsally), head usually with relatively few spots. The caudal fin is mainly straw colored, other fins mostly pale. (Pigment spots are not easily seen without magnification.)

COMMENTS ON THE HOLOTYPE OF *SYMPHYSANODON TYPUS*

Bleeker (1878) stated that he identified 118 species of fishes during a visit to the museum at Hamburg. Three of these, including *S. typus*, were described as new. In addition, Bleeker (1878) included *S. typus* in a list of the species examined in the museum at Hamburg. He also wrote that "M. le docteur J. G. Fischer, directeur de cet établissement, a eu la complaisance de m'adresser un premier envoi, composé de collections faites à la Nouvelle-Guinée, à Singapore, au Japon, en Chine et à l'île Maurice." (There is no indication as to which species were sent to Bleeker nor whether they were sent as a loan or as a gift.)

Whitehead, Boeseman, and Wheeler (1966) stated ". . . there is no evidence that Bleeker parted with specimens from his own personal collection after his return to Holland in 1860, except in the case of the British Museum sale. Neither is there any evidence that he did so before this date." They also noted that ". . . types contained in material on loan from other institutions were always stated by Bleeker to have been returned."

[4] This measurement not taken on holotype.

A. C. Wheeler and M. Boeseman informed me that they could not find any specimens listed as *S. typus* in the collections of the British Museum (Natural History) (Wheeler, in litt., October 27, 1966) and Rijksmuseum van Natuurlijke Historie (Boeseman, in litt., August 7, 1967). In addition, Boeseman wrote that he did not find *S. typus* listed in Bleeker's Auction Catalogue, 1879. From the preceding it seems that if type material of *S. typus* were sent to Bleeker, it was sent on loan and later returned. All of the type material of *S. typus*, then, should be at Hamburg.

Ladiges et al. (1958) listed a specimen (at Hamburg) cataloged as ZSZM H 398 as the "lectotype (holotype?)" of *Symphysanodon typus* Bleeker, 1878. This is apparently the only reference to a "lectotype" of this species, and, although it was not clearly stated, I assume that this was an attempt to designate ZSZM H 398 as the lectotype of *S. typus*. This attempt was apparently based on the lack of a definite statement by Bleeker (1878) as to the number of specimens he referred to in preparing his original description. In a few places in the original description of *S. typus* it appears as if Bleeker had more than one specimen at hand, but at the end of the description he gave the length of the described specimen ("Longitudo speciminis descripti") as 151‴ (which apparently means 151 mm. total length). In view of his mentioning the length of the described specimen, I think that Bleeker based his description on only one specimen. This position is supported by the facts that the Hamburg specimen (ZSZM H 398) appears to be almost equal in total length (147 + mm.) to Bleeker's specimen and it is the only type specimen of *S. typus* known. I regard this specimen (ZSZM H 398) as the holotype of *S. typus*.

SYNONYMY

Bleeker published two descriptions and two illustrations of *Symphysanodon typus* (1878: 61, pl. 3, fig. 1, and 1880: 28, pl. 5, fig. 2). The descriptions are apparently of the same material. The illustrations, although not identical, are so similar that one may be a copy of the other, and each is a good likeness of the holotype of *S. typus* (ZSZM H 398).

I examined the holotype of *S. typus* (ZSZM H 398), the two syntypes of *Propoma roseum* (BMNH 1879.5.14.164–5), and the holotype of *Rhyacanthias carlsmithi* (USNM 84099), and found that they are conspecific.

Günther (1880) did not clearly indicate the number of specimens upon which he based his original description of *P. roseum*. In two instances he presented body proportions in a manner implying that he had two specimens, whereas he later stated "Length of specimen, 5½ inches." Because the two syntypes of *P. roseum* are almost the same length (105 and 107 mm. SL; at least 5½ inches total length), length cannot be used as a criterion for determining which was intended when Günther gave length of specimen. He described the spine at the angle of the preopercle as flat and projecting. The syntype of 107 mm. SL has a spine at the angle of the left preopercle similar to that described by Günther, but the one of 105 mm. SL lacks a projecting spine at the angle of either preopercle. Except for the caudal fin, the specimen of 107 mm. SL is in better condition than the one of 105 mm. SL. I, therefore, designate as the lectotype of *Propoma roseum* the specimen of 107 mm. SL, which retains BMNH 1879.5.14.164–5; the paralectotype, the specimen of 105 mm. SL, has been assigned a new catalog number (BMNH 1968.8.1.2).

SEXUAL DIMORPHISM

External sexual dimorphism has not been reported for *Symphysanodon typus* and did not exist in the specimens of this species that I examined.

COMPARISONS

Symphysanodon typus may be separated from both *S. octoactinus* and *S. katayamai* by its more slender body, from *S. katayamai* by its shorter depressed anal fin, from *S. maunaloæ* by its possession of more pored scales in the lateral line, and from *S. berryi* by its usual possession of more pored scales in the lateral line and by differences in certain body proportions (see keys). The relation of numbers of total gill rakers on the anterior gill arch to pored lateral-line scales may be used to separate specimens of *S. typus* from those of the other species of the genus (table 1).

DISTRIBUTION

I examined specimens of *Symphysanodon typus* from all of its known localities of capture: New Guinea, Kai Islands, Philippine Islands, and Hawaii. Depth data are available for only two collections—65 fath. (119 m.) off the Philippine Islands and apparently 129 fath. (236 m.) off Kai Islands. Gosline and Brock (1960) stated that *S. typus* ". . . apparently lives well offshore . . ." and that it ". . . has never been seen in the market and has been recorded from Hawaii only on the basis of specimens killed by lava flows." *S. typus* is known from Hawaii only from specimens killed by lava flows. (Gosline, Brock, Moore, and Yamaguchi, 1954, discussed the fish kill resulting from the 1950 eruption of Mauna Loa.)

MATERIAL EXAMINED

I examined 12 specimens, 50 to 165 mm. SL.

Holotype

ZSZM H 398 (112 mm. SL), New Guinea.

Other Material

BMNH 1879.5.14.164–5 (1 specimen, 107 mm. SL; herein designated as the lectotype of *Propoma roseum*), off Kai Islands, *Challenger* station 192.[5] ..... BMNH 1968.8.1.2 (1, 105; the paralectotype of *P. roseum*) from same station as lectotype of *P. roseum*. ..... BMNH 1890.2.26.30 (1, 106), off Kai Islands?, locality of capture not definitely known, but probably from same locality (or general area) as the type specimens of *P. roseum*. ..... UW 12413 (6, 50–80), off the coast of Cavite Province, Luzon, in the south entrance to Manila Bay, Philippine Islands, 65 fath. (119 m.), by beam trawl, October 2, 1948. ..... USNM 84099 (1, ca. 148; holotype of *Rhyacanthias carlsmithi*), off a lava flow from Mauna Loa, Alika, Kau District, Hawaii, by Tom Reinhardt, October 1919 (probably October 6). ..... UH uncataloged (1, 165), picked up off lava flow, Kona, Hawaii, FWS vessel *Henry O'Malley*, June 3, 1950.

[5] Günther (1880) gave the following for *Challenger* station 192: off Kai Islands, 129 fath. Tizard, Moseley, Buchanan, and Murray (1885: 556) stated "The two trawlings, taken in 129 to 140 fathoms (Station 192). . ." and on p. 1012 (op. cit.) gave the data for *Challenger* station 192 as lat. 5° 49′ 15″ S., long. 132° 14′15″ E., 140 fath., September 26, 1874. According to U.S. Naval Oceanographic Office chart H.O. 5592, this position is in the Kai Islands—ca. 7 nautical miles SE. of Taam and ca. 13 nautical miles NW. of Kai Tanimbar.

SYMPHYSANODON KATAYAMAI NEW SPECIES

Figure 2; tables 1 to 4

Symphysanodon typus (non Bleeker, 1878), Kamohara and Katayama, 1959: 2, fig. 2 (synonymy in part of *S. typus* and in part of *S. maunaloæ;* description and illustration representing *S. katayamai* from Japan; distribution referring in part to *S. typus,* in part to *S. maunaloæ,* and in part to *S. katayamai*). ..... Katayama, 1960: 168, pl. 86 (synonymy referring in part to *S. typus,* in part to *S. maunaloæ,* and in part to *S. katayamai;* description and illustration representing *S. katayamai;* distribution referring in part to *S. typus,* in part to *S. maunaloæ,* and in part to *S. katayamai*). ..... Anderson, 1967: 2, 11 (compiled meristic data referring in part to *S. typus,* in part to *S. maunaloæ,* and in

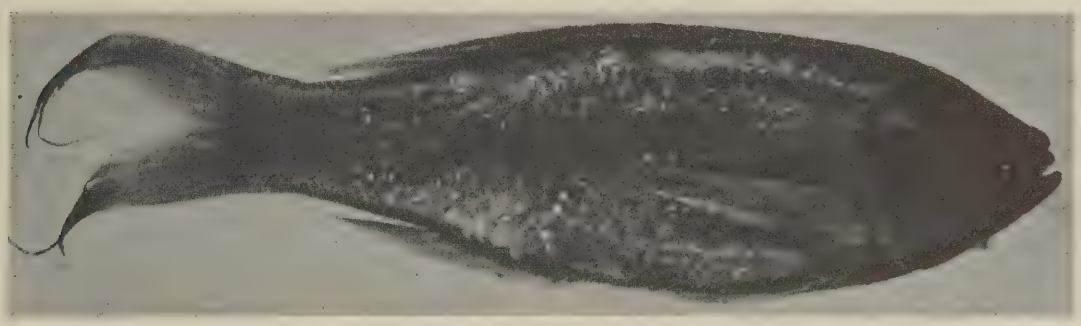

FIGURE 2.—Holotype of *Symphysanodon katayamai* (ZIKU 8206), 163 mm. SL.

part to *S. katayamai;* distribution referring in part to *S. typus,* in part to *S. maunaloæ,* and in part to *S. katayamai*). ..... Katayama, 1968: 105, figs. 1 to 5 (comments on osteology and systematic position).

DIAGNOSIS

Body relatively deep, the depth about 31 percent SL. First pelvic soft ray only slightly produced, not extending to anal fin. Anal fin longer than in other species of *Symphysanodon,* length of depressed anal fin about 39 percent SL. Caudal fin deeply forked, both lobes produced into filaments. Anal soft rays 7. Gill rakers 11 + 24—total 35. Pored lateral-line scales 50.

DESCRIPTION OF THE HOLOTYPE

Maxillary extending posteriorly to beneath posterior part of eye. Length of upper jaw contained in length of mandible 1.00 time. Dorsal profile convex, curving gently to above posterior portion of eye, and rather steeply from this point forward to tip of snout; a slight concavity above nostril region; interorbital region convex; ventral profile convex. Small teeth present in an elliptical patch on vomer and in narrow bands on palatines and ectopterygoids, no teeth apparent on mesopterygoids. Vertical limb of preopercle smooth except for a few small serrae; horizontal limb of preopercle smooth; angle of preopercle slightly produced posteriorly—possibly the remnant of a spine or spinelike process. Anterior part of snout with scales; a single scale present in midline of anterior part of gular region, remainder of gular region without scales; no scales apparent on branchiostegal membranes.

Counts

The following counts are repeated in tables 2, 3, and 4. Dorsal-fin rays IX, 10. Anal-fin rays III, 7. Pectoral-fin rays 16. Gill rakers 11 + 24 —total 35. Pored lateral-line scales 50. Sum of total number of gill rakers on anterior gill arch plus number of pored lateral-line scales 85.

Measurements

Selected measurements are presented in percentage of standard length. Length of head 27.2. Depth of head 21.8. Length of snout 7.3. Horizontal diameter of fleshy orbit 7.4. Width of suborbital 1.3. Height of cheek 7.3. Length of upper jaw 13.5. Length of mandible 13.6. Width of bony interorbital 8.1. Depth of body 31.1. Least depth of caudal peduncle 14.0. Pectoral fin reaching a vertical through base of first dorsal soft ray; length of longer pectoral fin 28.2. Pelvic fin reaching anterior portion of vent; first pelvic soft ray not greatly produced. Length of longer pelvic fin 26.6. Length of base of anal fin 18.1. Length of depressed anal fin 38.9. Lengths of dorsal spines: first 6.2, second 9.4, third—damaged, fourth—damaged, longest (sixth) 13.0, last—damaged. Lengths of anal spines: first >5.5—tip broken, second 9.8, third >10.5—tip broken. Caudal fin deeply forked, both lobes produced into filaments; filaments not produced to the extent of those on some large males of *S. berryi.* Length of upper lobe of caudal fin ca. 58.0. Length of lower lobe of caudal fin ca. 56.0.

Coloration

Kamohara and Katayama (1959, under *S. typus*) described the coloration of this species in Formalin[6] (presumably shortly after capture) as "reddish, a broad longitudinal orange band on the side of body; dorsal yellowish; tip of each lobe of caudal yellowish."

After more than 10 years in Formalin the holotype has faded to a light straw color without any distinctive concentrations of pigment.

OTHER SPECIMENS AND OTHER DESCRIPTIONS

Kamohara and Katayama (1959) described three specimens, 164 to 181 mm. (presumably SL), from Kashiwajima, Kochi Prefecture, Japan, under the name *Symphysanodon typus* Bleeker, 1878. Katayama (1960) repeated (with slight variation) the description given by Kamohara and Katayama. One of the three specimens (ZIKU 8206) mentioned by Kamohara and Katayama (1959) is described herein as the holotype of *Symphysanodon katayamai.* In most respects the earlier descriptions of Japanese *Symphysanodon* agree with the holotype of *S. katayamai,* and in all but two of the meristic characters (numbers of pectoral-fin rays and gill rakers) the count given in the earlier descriptions is identical with that of the holotype. (Pectoral-fin rays were given as 16 or 17, the holotype has 16; gill

[6] The use of trade names in this publication does not imply endorsement of commercial products.

rakers as 11 or 12 + 22 or 23, total 33 to 35, the holotype has 11 + 24, total 35.)

Another of the specimens (YU uncataloged) mentioned by Kamohara and Katayama (1959) was made available to me on loan. This is the specimen on which Katayama (1968) based an osteological study. Because it had been dissected, little of its external morphology could be studied. However, in its extant characters it appears to be conspecific with the holotype of *S. katayamai* (ZIKU 8206). Katayama reported small teeth on the mesopterygoid of this specimen (YU uncataloged). I did not see teeth on the mesopterygoids of the holotype (ZIKU 8206), and the skull was missing from the dissected specimen. Katayama (1968) recorded the number of vertebrae in the dissected specimen as 11 + 14 = 25. My count of the vertebrae from a radiograph of the same specimen is 10 + 15 = 25. This discrepancy is due to differences in determining which vertebra is the first caudal vertebra. (I considered the most anterior vertebra possessing a hemal spine associated with pterygiophores of the anal fin as the first caudal vertebra.)

The third specimen mentioned by Kamohara and Katayama is in the collections of the Zoological Institute, Kochi University (Kochi, Japan). Although I have not seen this specimen, I presume it to be a representative of *S. katayamai.*

SEXUAL DIMORPHISM

Sexual dimorphism is unknown in *Symphysanodon katayamai.*

COMPARISONS

Symphysanodon katayamai may be readily distinguished from other species of the genus by its longer depressed anal fin. The relation of numbers of total gill rakers on the anterior gill arch to pored lateral-line scales may be used to separate *S. katayamai* from all other species of *Symphysanodon* except *S. berryi* (table 1).

DISTRIBUTION

Symphysanodon katayamai is known only from off Kashiwajima, Kochi Prefecture, Japan. No data on the depths inhabited by this species are available.

ETYMOLOGY

This species is named for Masao Katayama, Yamaguchi University, Yamaguchi City, Japan, who made it possible for me to examine specimens of *Symphysanodon* from Japan.

MATERIAL EXAMINED

Holotype

ZIKU 8206 (163 mm. SL), collected off Kashiwajima, Kochi Prefecture, Japan, by S. Noda, K. Amaoka, and T. Hirata, October 15, 1957.

Other Material, Not Considered as Type Material

YU uncataloged (one dissected specimen), data the same as those for holotype. Because this specimen was extensively dissected, I do not consider it a type specimen.

SYMPHYSANODON MAUNALOAE NEW SPECIES

Figure 3; tables 1 to 4

Rhyacanthias species, Jordan, 1921: 648–649, fig. 4 (description of a small specimen, 3⅔ inches in total [?] length, assumed to be the young of *Rhyacanthias carlsmithi;* comments on three other specimens, 2½ to 4 inches in total [?] length, referred with doubt to *R. carlsmithi;* illustration, labeled as *Rhyacanthias carlsmithi* (young), presumably of one of the aforementioned specimens; killed by lava flow from Mauna Loa off Alika, Kau District, Hawaii).

Symphysanodon typus (non Bleeker, 1878), Fowler, 1928: 186 (synonymy of *S. typus;* description of a small specimen, 58 mm. total [?] length, from Alika, Kau District, Hawaii, erroneously considered as a paratype of *Rhyacanthias carlsmithi*). ..... Weber and de Beaufort, 1936: 309, fig. 65 (synonymy referring in part to *S. typus* and in part to *S. maunaloæ,* compiled description [probably representing *S. typus*], illustration [of *Propoma roseum* (= *S. typus*) after Günther, 1880], and distribution referring to *S. typus* and in part to *S. maunaloæ*). ..... Gosline and Brock, 1960: 183–184, 327 (probably in part; partial synonymy of *S. typus;* characters which can be used to identify *Symphysanodon;* Hawaii). ..... Anderson, 1967: 2, 11 (compiled meristic data referring in part to *S. typus,* in part to

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FIGURE 3.—Holotype of *Symphysanodon maunaloae* (USNM 204389, formerly HBL uncataloged), 69 mm. SL.

S. maunaloæ, and in part to *S. katayamai;* distribution referring in part to *S. typus*, in part to *S. maunaloæ*, and in part to *S. katayamai*).

DIAGNOSIS

Body slender, the depth 21.3 to 25.8 percent SL. First pelvic soft ray well produced in a few specimens, but only slightly produced in most (not extending to anal fin). Anal fin short, length of depressed anal fin ca. 24.0 to 29.2 percent SL. Caudal fin deeply forked, both lobes produced, but apparently never produced into excessively long filaments. Anal soft rays 7. Gill rakers 9 to 11 + 22 to 26—total 31 to 37. Pored lateral-line scales 43 to 47.

DESCRIPTION

Maxillary extending posteriorly to about middle of eye or a little beyond. Length of upper jaw contained in length of mandible 0.93 to 1.09 times. Interorbital region flattened. No teeth apparent on vomer, palatines, or pterygoids. Small serrae on vertical limb of preopercle, horizontal limb almost smooth or with a few serrae, mainly near angle; a spine or spinelike process at angle (spine or spinelike process often serrate). No scales on anteriormost part of snout; apparently a few scales in midline of anterior part of gular region in a specimen of 51 mm. SL (no other indications of scales in gular region of this specimen), scales not apparent in gular region of other specimens; frequently one to several scales present on membrane between the third and fourth branchiostegal rays, no other scales apparent on branchiostegal membranes.

Counts

Frequency distributions for the following counts are given in tables 2, 3, and 4. Dorsal-fin rays IX, 10 (IX, 9 on three specimens). Anal-fin rays III, 7. Pectoral-fin rays 15 to 17. Gill rakers 9 to 11 + 22 to 26—total 31 to 37. Pored lateral-line scales 43 to 47. Sum of total number of gill rakers on anterior gill arch plus number of pored lateral-line scales of individual specimens 76 to 81, 83.

Measurements

Ranges of selected measurements are presented in percentage of standard length followed by the value for the holotype of *S. maunaloæ* in parentheses. Length of head 32.0 to 35.6 (34.0). Depth of head 19.5 to 24.0 (21.0). Length of snout 6.4 to 8.2 (7.3). Horizontal diameter of fleshy orbit 10.3 to 14.0 (ca. 12.8). Width of suborbital ca. 0.6 to 1.0 (0.6). Height of cheek 3.8 to 5.6 (4.2). Length of upper jaw 12.5 to 15.1 (14.7). Length of mandible 12.5 to 15.7 (14.5). Width of bony interorbital 7.3 to 9.3 (8.3). Depth of body 21.3 to 25.8 (23.7). Least depth of caudal peduncle 9.6 to 11.9 (10.5). Pectoral fin usually reaching a vertical through base of first or second dorsal soft ray; length of longer pectoral fin 24.3 to 28.1 (26.1). Pelvic fin usually not extending to anal fin, but the first pelvic soft ray produced at least as far as middle of anal fin in several speci-

mens (the medial branch of the first pelvic soft ray reaching approximately to the distal end of the depressed anal fin in three specimens). Length of longer pelvic fin ca. 21.9 to >54 (>40). Length of base of anal fin 13.5 to 16.1 (14.4). Length of depressed anal fin ca. 24.0 to 29.2 (26.7). Lengths of dorsal spines: first 4.3 to 7.3 (6.2), second 10.2 to 13.6 (13.2), third 13.6 to 17.4 (16.5), fourth 15.8 to 18.7 (17.7), longest dorsal spine the fourth on all specimens examined, last 10.7 to 14.5 (14.1). Lengths of anal spines: first 4.0 to 5.5 (5.1), second 10.7 to 14.6 (13.1), third 12.7 to 15.6 (14.8). Caudal fin deeply forked, both lobes produced, but apparently never produced into excessively long filaments. Length of upper lobe of caudal fin ca. 31.2 to ca. 48.9 (39.0). Length of lower lobe of caudal fin ca. 30.0 to ca. 43.1 (>30).

Coloration

Paul J. Struhsaker (personal communication, July 1969) made the following observations on specimens of *S. maunaloæ* collected during *Townsend Cromwell* cruise 35 at station 12 "light reddish over upper parts and caudal; iris pink; darkish vertical bar just behind operculum and above pectoral; also dark bar between eyes."

Jordan (1921) wrote concerning one specimen (designated as *"Rhyacanthias,* species") "Color plain, probably red in life" and later concerning three other specimens (of *"Rhyacanthias,* species") ". . . the back is quite dark in color, made so by a multitude of dark punctulations; the upper fins and caudal also dusky, scales on opercle with a dusky area at base."

Specimens in alcohol have dark punctulations scattered profusely over body (pigment more heavily concentrated dorsally than ventrally). Most individuals are more heavily pigmented in an area which extends for a few scale rows above and below the anteriormost lateral-line scales. Larger, darker flecks of pigment are usually present in irregular rows on sides of body and in two rows on dorsal surface of body anterior and posterior to dorsal fin. The dorsal fin usually has considerable pigment distally; both lobes of caudal fin usually pigmented; other fins mostly pale.

SYNONYMY

Jordan (1921) in a separate section after his description of *Rhyacanthias carlsmithi* described —under the heading *"Rhyacanthias,* species"— a small specimen of 3⅓ inches (ca. 93 mm.) total [?] length, which he assumed to be the young of *R. carlsmithi.* Because Jordan gave the lateral-line scale count as 47—"as nearly as can be counted," this specimen is probably one of *S. maunaloæ.*

Jordan (1921) mentioned three other specimens (under the heading *"Rhyacanthias,* species"), 2½ to 4 inches (ca. 64–ca. 102 mm.) in total [?] length, which he referred with doubt to *R. carlsmithi.* There are three specimens of *Symphysanodon* in the U.S. National Museum (USNM 84101), ca. 42 to ca. 63 mm. SL, from Hawaii that have been labeled as paratypes of *R. carlsmithi.* Because Jordan designated no paratypes and gave no indication that he considered any specimen as a paratype of *R. carlsmithi,* these are not paratypes, but are probably three of the specimens Jordan (1921) mentioned under *"Rhyacanthias,* species." These specimens (USNM 84101) are in such poor condition that it is difficult to identify them to species; however, on the basis of numbers of gill rakers they probably are specimens of *S. maunaloæ.*

Fowler (1928) described a specimen, 58 mm. total [?] length, from the Bishop Museum (no catalog number given) under *Symphysanodon typus* and erroneously stated that it was a paratype of *Rhyacanthias carlsmithi.* I examined a specimen (ca. 49 mm. SL, 54 + mm. total length) of *Symphysanodon maunaloæ* from the Bishop Museum (BPBM 3982), presumably the specimen described by Fowler, and probably one of the specimens Jordan (1921) mentioned under *"Rhyacanthias,* species."

Jordan (1921) gave the catalog number of the specimen of *Rhyacanthias* of 3⅓ inches (see above) as USNM 24101, but gave no reference to a collection for the three specimens of 2½ to 4 inches. The reference to USNM 24101 is in error (the USNM catalog lists 24101 as *Hemilepidotus* sp. from Alaska); USNM 84101 must have been intended. Because the three specimens at the U.S. National Museum and the one at the Bishop Museum were collected by the same individual at apparently the same time and locality as that of the holotype of *Rhyacanthias carlsmithi,* they are with the greatest likelihood the

four small specimens referred to by Jordan (1921) under "*Rhyacanthias*, species."

SEXUAL DIMORPHISM

Seven specimens of *Symphysanodon maunaloæ* (62–86 mm. SL) have the pelvic fin well produced (with the medial branch of first pelvic soft ray reaching anterior part of base of anal fin or beyond), whereas in the other specimens (47–86 mm. SL) the pelvic fin, although usually produced, falls short of the anal fin. I attempted to determine the sex of several individuals, but, because of the relatively small size of the specimens, had only limited success. It seems, however, that the well-produced pelvic fin is a male characteristic (as it is in *S. berryi*).

COMPARISONS

Symphysanodon maunaloæ is easily distinguished from *S. katayamai* and *S. octoactinus* by its more slender body, from *S. katayamai* by its shorter depressed anal fin, and from *S. typus* and *S. berryi* by its possession of fewer pored scales in the lateral line. In addition, the relation of numbers of total gill rakers on the anterior gill arch to pored lateral-line scales may be used to separate specimens of *S. maunaloæ* from specimens of the other species of *Symphysanodon* (table 1).

DISTRIBUTION

Symphysanodon maunaloæ has been collected only off the Hawaiian Islands. The only information available on the depths inhabited by *S. maunaloæ* is from one trawl-station off the northeastern coast of the island of Hawaii (average depth to bottom at this station 130 fath. (238 m.)) and one off the southern coast of Lanai (122 fath. (223 m.)). The other collections of this species were made off lava flows from Mauna Loa. (Gosline, Brock, Moore, and Yamaguchi (1954) discussed the fish kill resulting from the 1950 eruption of Mauna Loa.)

ETYMOLOGY

This species is named for the active volcano Mauna Loa.

MATERIAL EXAMINED

I examined 30 specimens, ca. 42 to ca. 86 mm. SL.

Holotype

USNM 204389, formerly HBL uncataloged, (69 mm. SL), off northeastern coast of island of Hawaii, trawl set: lat. 20°07′ N., long. 155°25′ W., trawl hauled in: lat. 20°08′ N., long. 155°28′ W., average depth to bottom 130 fath. (238 m.), *Townsend Cromwell* cruise 35, station 12, March 31, 1968.

Paratypes

15 specimens, 62 to 86 mm. SL, from same station as holotype, formerly HBL uncataloged; USNM 204388 (12, 63–86) and BPBM 9779 (3, 62–86). ..... BPBM 9778, formerly HBL uncataloged, (1, 84), off southern coast of Lanai in Kealaikahiki Channel, Hawaiian Islands, lat. 20° 43′ N., long. 156° 49′ W., 122 fath. (223 m.), *Townsend Cromwell* cruise 33, station 25, November 4, 1967. ..... UH uncataloged (9, 47–62), collected off lava flow from Mauna Loa, Kona, Hawaii, by Gosline, Hayes, Keen, and Ellis, June 7, 1950. A total of 25 paratypes, 47 to 86 mm. SL.

Other Material, Not Part of the Type Series

BPBM 3982 (1, ca. 49), Alika, Kau District, Hawaii, by Tom Reinhardt, October 1919 (probably October 6). ..... USNM 84101 (3, ca. 42–ca. 63), off lava flow from Mauna Loa, Hawaii, collected by Tom Reinhardt, October 1919 (probably October 6). These specimens (BPBM 3982 and USNM 84101) were in poor condition and not considered during the preparation of the description of the species.

SYMPHYSANODON BERRYI NEW SPECIES

Figure 4; tables 1 to 4

DIAGNOSIS

Body slender, the depth 22.3 to 28.2 percent SL. First pelvic soft ray noticeably produced in males more than ca. 85 mm. SL, extremely filamentous in large males. Anal fin short, length of depressed anal fin 22.8 to ca. 27.6 percent SL. Caudal fin deeply forked, the upper and lower lobes produced into long filaments in large males. Anal soft rays 7. Gill rakers 9 to 12 + 24 to 28—total 34 to 39. Pored lateral-line scales 48 to 52.

FIGURE 4.—Holotype of *Symphysanodon berryi* (USNM 204086), a male, 115 mm. SL.

DESCRIPTION

Maxillary usually extending posteriorly to beyond middle of eye. Length of upper jaw contained in length of mandible 0.92 to 1.00 time. Interorbital region flattened. No teeth apparent on vomer, palatines, and pterygoids. Dentition better developed and coarser in males than in females. Serrae on vertical limb of preopercle usually well developed; horizontal limb with fewer serrae (mostly near angle) or sometimes almost smooth; usually a single spine (most frequently serrate, often bifid) or spinelike process at angle. Anterior part of snout without scales; scales usually absent (or at least not apparent) on gular region and branchiostegal membranes; on a very few specimens a number of scales present in mid-line of anterior part of gular region, on some others extremely small scales may be embedded in this region; a few specimens with a scale (rarely two) on membrane between third and fourth branchiostegal rays (rarely on membrane covering the third or fourth branchiostegal ray).

Counts

Frequency distributions for the following counts are given in tables 2, 3, and 4. Dorsal-fin rays IX, 10 (VIII, 11 on one specimen and IX, 9 on one). Anal-fin rays III, 7. Pectoral-fin rays 16 to 18. Gill rakers 9 to 12 + 24 to 28—total 34 to 39. Pored lateral-line scales 48 to 52. Sum of total number of gill rakers on anterior gill arch plus number of pored lateral-line scales of individual specimens 83 to 90.

Measurements

Ranges of selected measurements are presented in percentage of standard length followed by the value for the holotype of *S. berryi* in parentheses. Length of head 30.7 to 36.0 (32.8). Depth of head 20.1 to 23.3 (23.1). Length of snout 6.2 to 8.9 (8.9). Horizontal diameter of fleshy orbit 10.0 to 13.2 (10.0). Width of suborbital 0.8 to 1.2 (1.1). Height of cheek 4.4 to 6.4 (5.7). Length of upper jaw 14.0 to 16.5 (14.6). Length of mandible 13.6 to 15.9 (14.2). Width of bony interorbital 7.2 to 9.0 (8.0). Depth of body 22.3 to 28.2 (26.1). Least depth of caudal peduncle 9.5 to 11.8 (11.6). Pectoral fin usually reaching a vertical through base of first or second dorsal soft ray; length of longer pectoral fin 23.7 to 27.2 (24.4). Pelvic fin usually not extending to vent in females; first pelvic soft ray noticeably produced in males more than ca. 85 mm. SL, increasing in length with increase in SL, extremely filamentous in large specimens; medial branch of first pelvic soft ray reaching past fork of caudal fin in some large males. Length of longer pelvic fin ca. 20.3 to >87 (ca. 54), varying in females from ca. 21.2 to 24.5 and in males from ca. 30.0 to >87 in specimens more than ca. 85 mm. SL. Length of base of anal fin 12.7 to 15.8 (14.9). Length of depressed anal fin 22.8 to ca. 27.6 (25.1). Lengths of dorsal spines: first 5.5 to 7.5 (6.7), second 10.1 to 12.3 (11.4), third 14.0 to 16.5 (15.4), fourth 16.0 to 18.9 (16.7), longest (fourth, fifth, or sixth—most frequently the fourth or fifth) 16.0 to 18.9 (16.7), last ca. 12.3 to >15.7 (14.2). Lengths of anal spines: first 3.3 to 5.6 (4.3), second 9.9 to 13.4 (11.6), third 11.1 to 15.0 (12.6). Caudal fin deeply forked; the upper and lower lobes produced into fila-

ments in large males (filaments becoming extremely long in largest males), increasing in length with increase in SL. Length of upper lobe of caudal fin ca. 29.4 to >128 (ca. 44), varying from ca. 30.1 to >35 in females more than ca. 80 mm. SL and from ca. 34.3 to >128 in males more than ca. 85 mm. SL. Length of lower lobe of caudal fin ca. 28.0 to >111 (ca. 39), varying from ca. 29.5 to >34 in females more than ca. 80 mm. SL and from ca. 32.4 to >111 in males more than ca. 85 mm. SL.

Values for depth of body, lengths of fins and fin-lobes, length of base of anal fin, and lengths of anal spines are based on measurements of more than 110 specimens; those for all other morphometric characters listed above on measurements of a graded size series.

Coloration

Live coloration is unknown, but a 35–mm. color photograph was taken shortly after capture of a male specimen (TABL 101317, 120 mm. SL) from *Silver Bay* station 5191. Iris silvery, except for a little orange on dorsal curvature, some dull yellow to dark gray on anterior curvature, a little light gray on ventral curvature, and considerable dark gray on posterior curvature. Head mostly bright orange. Body mainly bright orange, except ventrolateral surface of anterior end of body silver with some orange. Area beneath base of dorsal fin red-orange. Dorsal spines and soft rays mostly orange. First interradial membrane of dorsal fin red-orange; a somewhat triangular silvery area on proximal portions of second through sixth interradial membranes; an elliptical orange to red-orange area on proximal portions of seventh through ninth interradial membranes; distal part of membrane of soft dorsal fin dull orange; remainder of dorsal fin mostly dull yellow. Area above base of anal fin bright orange. Anal fin not clearly visible. Pectoral fin orange basally, rest of fin pale to silvery. Pelvic spine and filamentous first pelvic soft ray silvery, rest of pelvic fin orange proximally grading into light orange or pink and then into dull yellow distally. Outer rays (including filamentous ones) of both lobes of caudal fin red-orange; inner two or three rays of each lobe and midcaudal rays dull yellow to silvery distally (i.e., dull yellow to silvery inner area of caudal fin crescent shaped), orange proximally.

A less distinct, 35–mm. color photograph of a smaller specimen presumably from *Silver Bay* station 5191 shows no pronounced differences from the above description except that the fins (particularly the dorsal and pelvic fins) are paler.

A 35–mm. color photograph of a male specimen (TABL 101316, 134 mm. SL) from *Oregon* station 5414 shows some differences from the preceding description. Iris mostly orange. Head and fins much less brightly colored. Dorsolateral surface of body dull orange overlying pale blue. Ventrolateral surface of body mostly silvery with some pale blue on caudal peduncle.

All photographed specimens were collected during daylight. Those from *Silver Bay* station 5191 were photographed in sunlight, the one from *Oregon* station 5414 in artificial light (PROX-O-LITE). It is not known whether the differences in coloration mentioned are real or a result of differences in lighting used in the photography. (Frederick H. Berry and George C. Miller made the photographs, which are deposited in the collection of color slides at TABL.)

Thirty-one days after capture (and shortly after transfer to isopropyl alcohol) notes were made on the color remaining on the three specimens of *S. berryi* (TABL 101315, 92–99 mm. SL) collected by the *Undaunted* off British Honduras. Dorsal part of head with considerable orange on two specimens (females of 92 and 98 mm. SL). Dorsal part of body (particularly above lateral line) with much orange on the female of 98 mm. SL. Membrane of dorsal fin (particularly spiny dorsal) with much dark pigment on all three specimens. Filament of lower caudal lobe red on one specimen (a male of 99 mm. SL). Distal tip of upper caudal lobe with some dark pigment on both female specimens. Distal tip of lower caudal lobe with some dark pigment in female of 92 mm. SL.

In alcohol, specimens greater than ca. 80 to 90 mm. SL are usually a light straw color except for small spots of dark pigment usually arranged in irregular rows along the side of the body and in one or two (usually two) rows on the dorsal surface of the caudal peduncle; heavy

concentrations of smaller spots of dark pigment frequently apparent on opercle and preopercle and usually present in an area which extends for a few scale rows above and below the anteriormost lateral-line scales. Specimens less than ca. 80 to 90 mm. SL show a similar pattern of pigmentation, but usually are more heavily covered with the smaller spots of pigment, particularly on the head and dorsolateral surface of the body. The dorsal fin shows considerable dark pigment on most specimens less than ca. 100 to 110 mm. SL, mostly pale in larger specimens; the caudal fin usually has some dark pigment in specimens less than ca. 80 mm. SL, usually straw colored proximally and pale distally in specimens more than ca. 80 mm. SL; other fins pale. (Pigment spots may be difficult to distinguish on some specimens without magnification.)

PREVIOUS REFERENCE TO *SYMPHYSANODON BERRYI*

In an earlier publication (Anderson, 1967) I presented a key for the identification of two undescribed species of western Atlantic *Symphysanodon*. The species designated as "*Symphysanodon* sp. A" is *S. berryi*.

SEXUAL DIMORPHISM

The sex was determined on 108 specimens (56 males, 73–137 mm. SL, and 52 females, 67–123 mm. SL). The 52 males more than 84 mm. SL and one of 73 mm. SL have the first pelvic soft ray noticeably produced; many males of more than 100 mm. SL have the medial branch of the first pelvic soft ray produced into a long filament which reaches the base of the caudal fin or beyond. Most males of more than 100 mm. SL have the caudal fin lobes produced into long filaments. None of the females have the first pelvic soft ray or caudal fin lobes produced into long filaments. In addition, the dentition is better developed and coarser in males than in females. Two specimens (105 and 125 mm. SL) on which I was unable to determine the sex have the first pelvic soft ray well produced and, thus, may be presumed to be males. The other specimens on which the sex was not determined are small (49–83 mm. SL, most of them less than 70 mm. SL).

Sexual dimorphism was not observed in the other characters studied.

COMPARISONS

Symphysanodon berryi may be separated from *S. octoactinus* and *S. katayamai* by its more slender body and by its shorter depressed anal fin, from *S. maunaloæ* by its possession of more pored scales in the lateral line, and from *S. typus* by its usual possession of fewer pored scales in the lateral line and by differences in certain body proportions (see keys). The relation of numbers of total gill rakers on the anterior gill arch to pored lateral-line scales may be used to separate specimens of *S. berryi* from those of all other species of the genus except *S. katayamai* (table 1). *S. berryi* seems to differ from the other species of *Symphysanodon* (with the apparent exception of *S. maunaloæ*) in exhibiting pronounced sexual dimorphism.

DISTRIBUTION

S. berryi has been collected in the western Atlantic off the Bahamas, Dominican Republic, Puerto Rico, Tobago, Mexico, British Honduras, Honduras, and Nicaragua in 120 to 260 fath. (220–476 m.). Specimens of *S. berryi* were collected at *Pillsbury* station 582. The depth data for this station are 250 to 20 fath. (458–37 m.). According to Thomas H. Fraser (in litt., April 22, 1968), *Pillsbury* station 582 was made going up the slope at Arrowsmith Bank. The vessel turned sharply in about 20 fath. and terminated the tow in about 155 fath. (283 m.). The net probably did not fish as shallow as 20 fath.

One specimen of *S. berryi* was collected in company with one of *S. octoactinus* at *Gerda* station 693 off Grand Bahama Island in 160 to 150 fath. (293–274 m.).

ETYMOLOGY

This species is named for Frederick H. Berry, who first brought it to my attention and who has taught me, stimulated my interest, and encouraged me.

MATERIAL EXAMINED

I examined 136 specimens, 47 to 137 mm. SL.

Holotype

USNM 204086 (a male, 115 mm. SL), off southern coast of Great Inagua Island, Bahamas,

lat. 20°45′ N., long. 73°33′ W., 217 to 200 fath. (397–366 m.), *Oregon* station 5414, May 24, 1965.

Paratypes

43 specimens, 87 to 137 mm. SL, from same station as holotype: AM I. 15402–001 (1 specimen, 122 mm. SL), AMNH 28501 (2, 110–128), ANSP 112724 (2, 112–120), BPBM 7305 (1, 109), BMNH 1969.5.16.2–3 (2, 118–121), BOC 5988 (1, 125), CU 64262 (2, 109–119), IRSNB 474 (1, 133), LACM 30769–1 (2, 115–120), MCZ 46518 (2, 110–135), MNHN 1969–165 (2, 106–111), RMNH 26071 (1, 121), SU 67142 (2, 114–124), TABL 101316 (10, 93–134), TU 57443 (2, 116–120), UF 16425 (2, 112–125), UH uncataloged (1, 114), UMMZ 188888 (2, 92–112), USNM 204087 (3, 88–137), UW 200444 (1, 87), and ZSZM 4201 (1, 118). ..... UMML 2679 (4, 73–93), north of Little Bahama Bank, lat. 27°29′ N., long. 78°58′ W., 200 fath. (366 m.), *Combat* station 236, February 2, 1957. ..... UMML 20774 (1, 74), off southern coast of Grand Bahama Island, lat. 26°34′ N., long. 78°26–25′ W., 160 to 150 fath. (293–274 m.), *Gerda* station 693, July 21, 1965. ..... 26 specimens, 49 to 86 mm. SL, off eastern coast of the Dominican Republic, lat. 18°24′ N., long. 68°05′ W., 200 fath. (366 m.), *Silver Bay* station 5190, October 17, 1963; TABL 101313 (6, 56–83), UMML 15814 (17, 60–78), and USNM 204088 (3, 49–86). ..... 24 specimens, 71 to 120 mm. SL, off western coast of Puerto Rico, lat. 18°26.5′ N., long. 67°41′ W., 260 fath. (476 m.), *Silver Bay* station 5191, October 18, 1963; TABL 101317 (21, 71–120), and USNM 204089 (3, 96–108). ..... FMNH 66922 (1, 54), off the southern coast of Isla de Vieques, Puerto Rico, lat. 18°05′ N., long. 65°21′ W., 120 fath. (220 m.), *Oregon* station 2627, September 29, 1959. ..... 7 specimens, 75 to 102 mm. SL, off western coast of Puerto Rico, lat. 18°03′ N., long. 67°27′ W., 150 to 180 fath. (274–329 m.), *Oregon* station 2643, October 5, 1959; FMNH 66923 (4, 75–100) and UMML 7487 (3, 77–102). ..... UMML 7043 (2, 86–87), off western coast of Puerto Rico, lat. 18°14′ N., long. 67°20′ W., 210 fath. (384 m.), *Oregon* station 2646, October 5, 1959. ..... TABL 106432 (1, 81), off northwestern coast of Tobago, lat. 11°30′ N., long. 60°46′ W., 200 to 240 fath. (366–439 m.), *Oregon* station 5028, September 22, 1964. ..... UMML 23902 (6, 83–96), east of Arrowsmith Bank, off Quintana Roo, Mexico, lat. 21°10′ N., long. 86°18′ W., 250 to 20 fath. (458–37 m.), *Pillsbury* station 582, May 23, 1967. ..... TABL 101315 (3, 92–99), south southwest of Glovers Reef, off British Honduras, lat. 16°35′ N., long. 87°56′ W., 150 to 175 fath. (274–320 m.), *Undaunted* cruise 6703, station 76 (TABL 67–174), May 19, 1967. ..... FMNH 66918 (8, 80–119), off northeastern coast of Honduras, lat. 16°39′ N., long. 82°29′ W., 225 fath. (412 m.), *Oregon* station 1870, August 21, 1957. ..... FMNH 66919 (1, 99), off eastern coast of Nicaragua, lat. 11°31′ N., long. 83°09′ W., 150 fath. (274 m.), *Oregon* station 1903, September 9, 1957. ..... 6 specimens, 75 to 112 mm. SL, off eastern coast of Nicaragua, lat. 11°34′ N., long. 83°07′ W., 125 fath. (229 m.), *Oregon* station 1904, September 9, 1957; FMNH 66920 (5, 75–112) and FMNH 66921 (1, 108). A total of 133 paratypes, 49 to 137 mm. SL.

Other Material, Not Part of the Type Series

UMML 24751 (1, 47), collection data the same as that for UMML 23902. ..... TABL 106275 (1, 87), collection data the same as that for TABL 101317. These specimens (UMML 24751 and TABL 106275) were not considered during the preparation of the description of the species.

SYMPHYSANODON OCTOACTINUS NEW SPECIES

Figure 5; tables 1 to 4

DIAGNOSIS

Body deeper than in other species of *Symphysanodon*, the depth 33.4 to 36.0 percent SL. First pelvic soft ray not greatly produced. Anal fin short, length of depressed anal fin 28.5 to 32.3 percent SL. Caudal fin deeply forked, but the lobes apparently never greatly produced. Anal soft rays 7 or 8 (usually 8). Gill rakers 12 to 14 + 26 to 29—total 39 to 42. Pored lateral-line scales 45 or 46.

DESCRIPTION

Maxillary extending posteriorly to approximately middle of eye or a little beyond. Length

of upper jaw contained in length of mandible 1.04 to 1.13 times. Interorbital region flattened. A band of small toothlike irregularities on palatines of largest specimen (FMNH 66924, 108 mm. SL), teeth not apparent on palatines of other specimens; teeth not apparent on vomer or pterygoids. Preopercle almost smooth or with small serrae (particularly in region of angle); rarely with a spinelike process at angle. Anterior part of snout, most of gular region, and most of branchiostegal membranes without scales; often one to several scales present in midline of anterior part of gular region; frequently one to several scales present on the membrane covering the fourth branchiostegal ray.

Counts

Frequency distributions for the following counts are given in tables 2, 3, and 4. Dorsal-fin rays[7] IX or X, 9 or 10 (usually IX, 10). Anal-fin rays III, 7 or 8 (usually 8). Pectoral-fin rays 16 or 17 (usually 16). Gill rakers 12 to 14 + 26 to 29—total 39 to 42. Pored lateral-line scales 45 or 46. Sum of total number of gill rakers on anterior gill arch plus number of pored lateral-line scales of individual specimens 84, 86, 88.

Measurements

Ranges of selected measurements are presented in percentage of standard length followed by the value for the holotype of *S. octoactinus* in parentheses. Length of head 33.9 to 36.3 (34.6). Depth of head 27.4 to 30.9 (29.0). Length of snout 6.4 to 8.6 (7.6). Horizontal diameter of fleshy orbit 12.1 to 15.4 (14.4). Width of suborbital 0.6 to 1.0 (0.8). Height of cheek 5.6 to 8.0 (7.3). Length of upper jaw 14.4 to 16.5 (16.1). Length of mandible 16.0 to 18.4 (18.0). Width of bony interorbital 9.0 to 10.5 (9.9). Depth of body 33.4 to 36.0 (34.8). Least depth of caudal peduncle 12.0 to 13.2 (12.8). Pectoral fin usually reaching a vertical through base of third or fourth dorsal soft ray; length of longer pectoral fin 28.3 to >30.9 (30.5). Pelvic fin usually reaching anal fin; first pelvic soft ray not greatly produced. Length of longer pelvic fin ca. 25.8 to ca. 27.9 (ca. 25.8). Length of base of anal fin 16.5 to 18.8 (18.4). Length of depressed anal fin 28.5 to 32.3 (30.9). Lengths of dorsal spines: first 6.1 to 7.8 (>6.3), second 10.1 to 11.5 (10.7), third 12.8 to 14.7 (>13.1), fourth 13.8 to 16.5 (>15.6), longest (fifth, sixth, or seventh—most frequently the fifth) 15.4 to 18.4 (16.6), last 14.1 to 16.4 (15.2). Lengths of anal spines: first 7.0 to 9.1 (7.3), second 13.0 to 14.9 (14.4), third 14.9 to 18.0 (16.4). Caudal fin deeply forked, the lobes apparently never greatly produced (however, caudal fin damaged on most specimens). Length of upper lobe of caudal fin ca. 38.6 to >42.0 (ca. 41.4). Length of lower lobe of caudal fin ca. 37.2 to 39.1 (ca. 37.2).

[7] One specimen (UMML 11050, 58 mm. SL) has 10 dorsal spines. The ninth spine in the series appears to be intercalated between what would normally be the last two dorsal spines. It is shorter than either the spine anterior or posterior to it and arises abnormally close to the last spine.

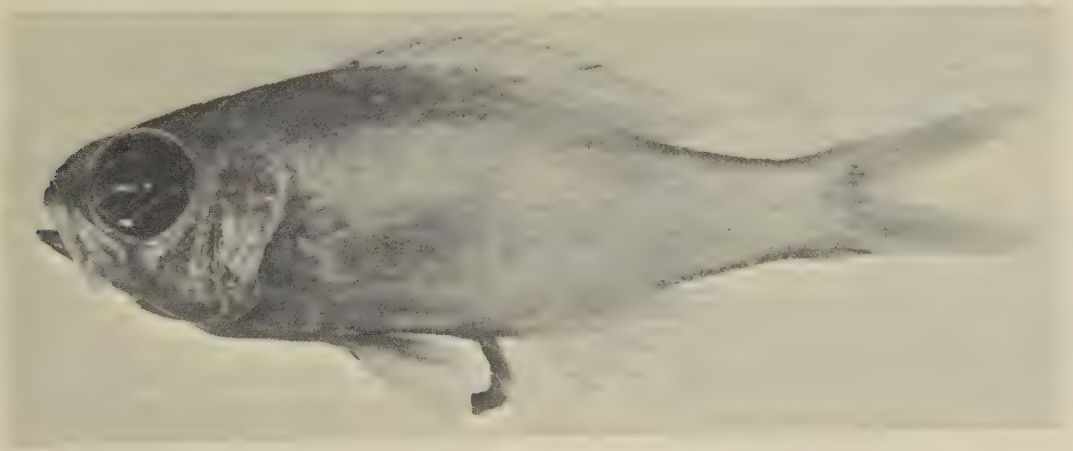

FIGURE 5.—Holotype of *Symphysanodon octoactinus* (USNM 204084, formerly UMML 20775), 79 mm. SL.

Coloration

No information is available on live coloration. In alcohol, specimens are a uniform straw color except for a variable number of small spots of dark pigment scattered over head and body (some larger spots of pigment usually present, mainly above the lateral line). Dorsal fin and proximal part of caudal fin usually have a considerable number of small spots of dark pigment (caudal fin of holotype with a very narrow dusky border distally); other fins mostly pale. (Pigment spots are not easily seen without magnification.)

PREVIOUS REFERENCE TO *SYMPHYSANODON OCTOACTINUS*

The species designated as "*Symphysanodon* sp. B" by Anderson (1967: 12) is *S. octoactinus*.

SEXUAL DIMORPHISM

No external evidence of sexual dimorphism was observed in *S. octoactinus*.

COMPARISONS

Specimens of *Symphysanodon octoactinus* may be readily distinguished from specimens of all other species of the genus by their deeper bodies, by their usual possession of an additional anal soft ray, and by the relation of number of total gill rakers on the anterior gill arch to number of pored lateral-line scales (table 1).

DISTRIBUTION

Symphysanodon octoactinus has been collected in the western Atlantic off the Bahamas, Puerto Rico, Nicaragua, and Panama in 85 to 160 fath. (156–293 m.). The holotype of *S. octoactinus* was caught along with one specimen of *S. berryi* at *Gerda* station 693 off Grand Bahama Island in 160 to 150 fath. (293–274 m.).

ETYMOLOGY

The name *octoactinus*, suggested by Albert Schwartz (Miami Dade Junior College), is from the Greek (octo, eight; actis, ray) and refers to the usual number of anal soft rays (eight) found in this species. This name should be considered as an adjective.

MATERIAL EXAMINED

I examined 19 specimens, 58 to 108 mm. SL.

Holotype

USNM 204084, formerly UMML 20775, (79 mm. SL), off southern coast of Grand Bahama Island, lat. 26°34′ N., long. 78°26–25′ W., 160 to 150 fath. (293–274 m.), *Gerda* station 693, July 21, 1965.

Paratypes

FMNH 66924 (1, 108 mm. SL), off western coast of Puerto Rico, lat. 18°24′ N., long. 67°15′ W., 100 fath. (183 m.), *Oregon* station 2655, October 6, 1959. ..... UMML 12273 (2, 69–85), off eastern coast of Nicaragua, lat. 12°32′ N., long. 82°25′ W., 85 fath. (156 m.), *Oregon* station 3577, May 23, 1962. ..... 15 specimens, 58 to 101 mm. SL, off northern coast of Panama, lat. 09°02′ N., long. 81°26′ W., 100 fath. (183 m.), *Oregon* station 3595, May 30, 1962; ANSP 112723 (1, 75), BMNH 1969.5.16.4 (1, 76), TABL 101314 (2, 69–101), UMML 11050 (8, 58–78), and USNM 204085 (3, 70–82). A total of 18 paratypes, 58 to 108 mm. SL.

ZOOGEOGRAPHY AND PHYLOGENY OF THE GENUS *SYMPHYSANODON*

All of the specimens of *Symphysanodon* known are from the western Pacific, central Pacific, or western Atlantic, and most specimens (155 of 200) are from a relatively small area in the western Atlantic (the Caribbean Sea and off the islands of the West Indies) from which a large number of collections have been made within the last 20 years.

Species of *Symphysanodon* show a marked predilection for moderate depths—65 to 260 fath. (119–476 m.)—around islands. The three Pacific species (*S. typus, S. katayamai*, and *S. maunaloæ*) have been captured exclusively off insular areas, whereas the two western Atlantic species (*S. berryi* and *S. octoactinus*) have been collected off both the Caribbean coast of continental America and off islands in the West Indies. Most of the specimens of *S. berryi* have been collected off islands in the West Indies, but most of those of *S. octoactinus* are from the Caribbean Sea off Central America.

Although depth data for Pacific *Symphysanodon* are meager (only four depth records, none for *S. katayamai*), these species may frequent somewhat shallower waters—65 to 130

fath. (119–238 m.)—than do the Atlantic species—85 to 260 fath. (156–476 m.). Of the Atlantic species, *S. berryi* has been found in deeper waters—120 to 260 fath. (220–476 m.)—than has *S. octoactinus*—85 to 160 fath. (156–293 m.).

When habitats suitable for *Symphysanodon* have been more extensively explored in the Pacific, Indian Ocean, and eastern Atlantic, more secure foundations for developing explanations for the patterns of distribution of the species of the genus will be available. However, from the accessible data, it seems that the genus may have evolved in the central western Pacific and spread northward to colonize the area off Japan and eastward to the Hawaiian Islands. If *Symphysanodon* arose in the western Pacific and spread to the central Pacific, two routes for invading the western Atlantic would have been available—one from the western Pacific via the Indian Ocean and eastern Atlantic and the other from the central Pacific via the eastern Pacific. The route via the eastern Pacific would have been shorter and less encumbered by land as a barrier.

On the basis of our fragmentary knowledge of *Symphysanodon,* it seems that the wide-ranging species, *S. typus,* may resemble the progenitor of the contemporary species of the genus more closely than do any of the other modern species and that some (perhaps all) of the modern species may be derivatives of a *typus*-like ancestor. Descent from a *typus*-like predecessor seems to have been the case for *S. maunaloæ* and perhaps also for *S. katayamai.*

The geographically well-separated species *S. typus* (western and central Pacific) and *S. berryi* (western Atlantic) are the most difficult to separate when morphological characters are used. Their similar morphology might be the result of parallelism (or convergence) within the genus or of slight divergence from a rather recent common ancestor. If *S. typus* and *S. berryi* have diverged comparatively recently, the more likely route for colonization of the western Atlantic by *Symphysanodon* would have been via the eastern Pacific.

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